Great Western Highway
Blackheath to Little Hartley

Appendix F
Human health

Limitations

Environmental Risk Sciences has prepared this report for the use of AECOM and Transport for NSW in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

It is prepared in accordance with the scope of work and for the purpose outlined in the Section 1 of this report.

The methodology adopted, and sources of information used are outlined in this report. Environmental Risk Sciences has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information contained in the reports provided for use in this assessment was false.

This report was prepared between March 2022 and January 2022 and is based on the information provided and reviewed at that time. Environmental Risk Sciences disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

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Annexures

Glossary of terms and abbreviations

Term	Meaning
A weighted decibels (dB(A))	The A weighting is a frequency filter applied to measured noise levels to represent how the human ear hears sounds. Adjustments are applied between 10Hz and 20 kHz. When an overall sound level is A-weighted it is expressed in units of dB(A) or dBA.
Acute or short-term exposure	Contact with a substance that occurs only once or for a short period of time, typically an hour or less, but may be up to 14 days.
Absorption	The process of taking in. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs.
Adverse health effect	A change in body function or cell structure that might lead to disease or health problems.
Background level	An average or expected amount of a substance or material in a specific environment, or typical amounts of substances that occur naturally in an environment.
Biodegradation	Decomposition or breakdown of a substance through the action of micro-organisms (such as bacteria or fungi) or other natural physical processes (such as sunlight).
Body burden	The total amount of a substance in the body. Some substances build up in the body because they are stored in fat or bone or because they leave the body very slowly.
Carcinogen	A substance that causes cancer.
Chronic or long-term exposure	Contact with a substance that occurs repeatedly over a long time, with the USEPA indicating defining this as exposures that occur for more than approximately 10% of a lifetime, Exposures that occur for less than 10% of a lifespan are considered sub-chronic.
Co-exposure	Exposure to more than one pollutant or stressor (such as noise) by a population
Combined	In the context of the health impact assessment, combined refers to the sum of exposures from different project impacts: such as impacts on health from emissions to air from the tunnel ventilation facilities plus impacts on health from changes in air impacts from surface roads; or impacts on health from changes in air quality plus impacts on health from changes in noise.
Cumulative	Total exposure, used in the health impact assessment to refer to exposures that include the background plus project, or to multiple different sources from the project
Decibel (dB)	A logarithmic scale is used to describe the level of sound, referenced to a standard level. It is widely accepted that a 3dB change in traffic noise levels (of the same character) is barely, if at all detectable; whereas a change of 5 dB is clearly noticeable. A 10 dB increase is typically considered to sound twice as loud (noting a change of -10 dB would typically sound half as loud).
Detection limit	The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.
Dose	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligrams (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An 'exposure dose' is how much of a substance is encountered in the environment. An 'absorbed dose' is the amount of a substance that actually gets into the body through the eyes, skin, stomach, intestines, or lungs.
Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].
Exposure assessment	The process of finding out how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and how much of the substance they are in contact with.

Term	Meaning
Exposure pathway	The route a substance takes from its source (where it began) to its end point (where it ends), and how people can come into contact with (or get exposed) to it. An exposure pathway has five parts: a source of contamination (such as chemical leakage into the subsurface); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching), and a receiver population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a completed exposure pathway.
Guideline value	A guideline value is a concentration in soil, sediment, water, biota or air (established by relevant regulatory authorities such as the NSW Department of Environment and Conservation (DEC), or institutions such as the National Health and Medical Research Council (NHMRC) Australia and New Zealand Environment and Conservation Council (ANZECC) and World Health Organisation (WHO)). The guideline value is used to identify conditions below which no adverse effects, nuisance or indirect health effects are expected. The derivation of a guideline value utilises relevant studies on animals or humans and relevant factors to account for inter- and intra-species variations and uncertainty factors. Separate guidelines may be identified for protection of human health, or the environment. Dependent on the source, guidelines have different names, such as investigation level, trigger value, ambient guideline etc.
Inhalation	The act of breathing. A hazardous substance can enter the body this way [see route of exposure].
Intermediate exposure duration	Contact with a substance that occurs for more than 14 days and less than a year [compare with acute exposure and chronic exposure].
L_{10}	The sound pressure level exceeded for 10% of the measurement period. The A-weighted form is denoted 'L_{A10}'.
$L_{A10(18h)}$	The $L_{A10(18\text{-hour})}$ noise level refers to the noise level exceeded for 10 per cent of the time during an 18-hour period (from 6am to midnight). This noise descriptor is calculated using the arithmetic average of the L_{A10} noise levels for each hour from 6am to midnight.
L_{den}	The average noise level over the day, evening and night (i.e. a 24-hour period).
L_{eq}	Equivalent continuous sound level. The constant sound level which, when occurring over the same period of time, would result in the receptor experiencing the same amount of sound energy. The A-weighted form is denoted 'L_{Aeq}'.
L_{night}	The average noise level over the night-time period, typically between 11pm or midnight and 6am.
LOAEL	Lowest-observed-adverse-effect-level - The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.
Metabolism	The conversion or breakdown of a substance from one form to another by a living organism.
Morbidity	A diseased condition or state or the incidence or prevalence of disease in a population
Mortality	Death, which may occur as a result of a range of reasons or diseases
NOAEL	No-observed-adverse-effect-level - The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.
Not measurable	The term "no measurable" or "not measurable" is used in this health impact assessment when referring to changes in air quality, noise or health outcomes in a population. For air quality and noise, a change that would be not be measurable is one where the estimated change in the concentration of the pollutant in ambient air, or noise, is so small that it could not be measured - i.e. within the error of the analytical method/measurement equipment. For health outcomes, it refers to exposures that are below a threshold so there are no health effects, or to changes in the number of people that may be affected (i.e. increase or decrease in deaths or hospitalisations) that is within the error/variability of the statistical measures (i.e. is not measurable).
Point of exposure	The place where someone comes into contact with a substance present in the environment [see exposure pathway].
Population	A group or number of people living within a specified area or sharing similar characteristics (such as occupation or age).
Receiver population	People who could come into contact with hazardous substances [see exposure pathway].
Risk	The probability that something would cause injury or harm.

Term	Meaning
Route of exposure	The way people come into contact with a hazardous substance. The three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact]
Toxicity	The degree of danger posed by a substance to human, animal or plant life.
Toxicity data	Characterisation or quantitative value estimated (by recognised authorities) for each individual chemical for relevant exposure pathway (inhalation, oral or dermal), with special emphasis on dose-response characteristics. The data is based on available toxicity studies relevant to humans and/or animals and relevant safety factors.
Toxicological profile	An assessment that examines, summarizes, and interprets information about a hazardous substance to determine harmful levels of exposure and associated health effects. A toxicological profile also identifies significant gaps in knowledge on the substance and describes areas where further research is needed.
Toxicology	The study of the harmful effects of substances on humans or animals.
Uncertainty factor	Mathematical adjustments for reasons of safety when knowledge is incomplete. For example, factors used in the calculation of doses that are not harmful (adverse) to people. These factors are applied to the lowest-observed-adverse-effect-level (LOAEL) or the no-observed-adverse-effect-level (NOAEL) to derive a minimal risk level (MRL). Uncertainty factors are used to account for variations in people's sensitivity, for differences between animals and humans, and for differences between a LOAEL and a NOAEL. Scientists use uncertainty factors when they have some, but not all, the information from animal or human studies to decide whether an exposure would cause harm to people [also sometimes called a safety factor].

Abbreviation	Term
AAQ	Ambient air quality
AQ	Air quality
ANZECC	Australia and New Zealand Environment and Conservation Council
ATSDR	Agency for Toxic Substances and Disease Register
BaP	Benzo(a)pyrene
BTEX	Benzene, toluene, ethylbenzene and total xylenes
CALD	Cultural and linguistic diversity
CEMP	Construction Environment Management Plan
CNVMP	Construction Noise and Vibration Management Plan
CO	Carbon monoxide
COPD	Chronic Obstructive Pulmonary Disease
DECCW	Department of Environment, Climate Change and Water
DPM	Diesel particulate matter
EC	European Commission
EIS	Environment Impact Statement
EPA	Environment Protection Authority
HIA	Health Impact Assessment
HHRA	Human Health Risk Assessment
IARC	International Agency for Research on Cancer
LGA	Local Government Area
LOR	Limit of Reporting
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
NO_2	Nitrogen dioxide
NPI	National Pollutant Inventory
OEHHA	Office of Environmental Health Hazard Assessment, California Environment Protection Agency (Cal EPA)
PAH	Polycyclic aromatic hydrocarbon
PIARC	Permanent International Association of Road Congresses
PM	Particulate matter
$PM_{2.5}$	Particulate matter of aerodynamic diameter 2.5 µm and less
PM_{10}	Particulate matter of aerodynamic diameter 10 µm and less
TBM	Tunnel boring machine
TCEQ	Texas Commission on Environmental Quality
TRV	Toxicity reference value
TSP	Total suspended particulate
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WHO	World Health Organization

Executive summary

E.1 Introduction

Transport for NSW (Transport) is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act) to upgrade the Great Western Highway between Blackheath and Little Hartley (the project). The project forms the central component of the Great Western Highway Upgrade Program (GWHUP).

Located around 90 kilometres northwest of the Sydney CBD, the project would comprise the construction and operation of new twin tunnels around 11 kilometres long between Blackheath and Little Hartley, with associated surface road upgrade works for tie-ins to the east and west of the proposed tunnel portals.

E.2 Purpose of this report

This technical report forms part of the environmental impact statement (EIS) for the project and provides an assessment of human health impacts for the project in accordance with the Secretary's Environmental Assessment Requirements (SEARs) issued by the NSW Department of Planning and Environment (DPE).

E.3 Methodology

A health impact assessment is a way of determining now, what the consequences to health (both positive and negative) of some future action (such as this project) may be. It draws on previous experience about impacts from road tunnels and surface motorways and their potential effects on people who live or work around them. It uses this information to predict the potential impacts of the project on community health.

In this case, this report includes a detailed review of potential impacts which may occur, who may be exposed to these impacts and whether there is potential for these impacts to result in adverse health effects or positive benefits within the local community. The health impact assessment presented in this report has been conducted in accordance with national guidance (enHealth 2012a, 2017; Harris et al. 2007), which has involved the following:

- review of predicted impacts associated with air quality, noise and vibration, public safety, contamination and social change during construction and operation of the project. In some cases, the issues identified, such as those during construction, are short-term and can be mitigated/managed through the implementation of specific management measures. For other impacts, such as those from operations or for extended periods of construction from a number of projects, the impacts may occur over a longer period of time and require a more detailed assessment of how these impacts affect health
- identification and characterisation of the community (including the presence of sensitive receptors such as childcare centres, aged care centres, schools and hospitals) who may be affected by these impacts
- assessment of air quality impacts on health including:
    - reviewing the key air pollutants (associated with vehicle emissions) that are predicted from the operation of the project (within the tunnel and outside the tunnel)

- identifying guidelines that are based on protection of the health of all members of the population for exposure to these pollutants over a short period of time as well as all day, every day
  - comparing the predicted impacts with the health based guidelines
  - undertaking a more detailed assessment of potential risks of changes in nitrogen dioxide and particulates, including fine particulate matter or $PM_{2.5}$ (particulate matter of aerodynamic diameter 2.5 microns (µm) and less) and coarse particulate matter or PM_{10} (particulate matter of aerodynamic diameter 10 µm and less). The assessment has addressed specific health effects (or health endpoints) associated with exposures to these pollutants. The assessment conducted has evaluated the impact of the project on these health endpoints within the local community
  - assessment of the potential for health issues for users of the tunnel
  - valuing/costing the impacts on health relevant to particulate matter based on the NSW Environment Protection Authority (NSW EPA) methodology
- assessment of noise and vibration impacts on health including:
  - reviewing the potential impacts that are predicted from the construction and operation of the project
  - characterising the health effects of noise
  - identifying guidelines that are based on the protection of the health and wellbeing (including sleep disturbance) during all phases of the project, both construction and operation
  - comparing potential impacts with the health based guidelines. Where the health based guidelines cannot be met, consideration of the implementation of mitigation/management measures
- assessment of public safety and contamination:
  - this has involved a qualitative assessment, providing an overview of the potential hazards that may affect public safety during construction and operation, including contamination. This review has considered the implementation of mitigation/management measures and whether these can minimise risks to the community
- assessment of other project changes on health:
  - this has involved a qualitative assessment. Aspects of the project that have the potential to result in impacts or changes in the community (including traffic, pedestrian and cycle access, property acquisitions and access, visual changes, community access/cohesion and economic impacts) have been evaluated with respect to potential effects on health and well-being. In addition, the equity of changes associated with the project has also been evaluated within the community.

An assessment of cumulative impacts on health, related to community exposure to a number of concurrent construction projects, has also been undertaken.

E.3 Conclusions

Health impacts associated with changes in air quality

The assessment has considered emissions to air from the project, where these may occur as a result of portal emissions or discharges from ventilation outlets. The assessment has considered emissions and impacts associated with typical traffic and peak or maximum traffic scenarios. In addition, a regulatory worst-case scenario has been considered.

In relation to potential impacts on health in relation to changes in air quality has concluded the following:

- Construction:
  - potential impacts on community health are considered to be low. The implementation of dust mitigation would further reduce potential exposures during construction works.
- Operations:
  - the project would result in some redistribution of traffic on surface roads, which would redistribute air emissions within the surrounding community
  - the redistribution of traffic on surface roads would result in an overall improvement in air quality in the community, for both ventilation options (portals and ventilation outlets)
  - localised health impacts from the project, for both ventilation options, and the redistribution of surface road traffic are considered to be low and acceptable and not measurable within the community
  - it is noted that the maximum localised/individual risk associated with exposure to particulate emissions is lower where the project design includes ventilation outlets. This is only the case for the maximum case traffic scenario, which only occurs around 4 days per year, and the regulatory worst case, which assumes the tunnel is full of vehicles at all times of the day, every day, which is unrealistic.
- In-tunnel exposures:
  - in-tunnel air guidelines for carbon monoxide and nitrogen dioxide would be adequately protective of the health of tunnel users. Short-duration exposures to higher levels of particulates should be minimised by providing advice to motorists to keep windows closed and switch vehicle ventilation to recirculation.

Health impacts associated with changes in noise and vibration

The assessment undertaken in relation to health impacts that may occur due to changes in noise and vibration resulting from the project has concluded the following:

- Construction:
  - noise impacts have been identified during construction works, which would require the implementation of mitigation measures
  - where there is the potential for construction works to occur at locations where vibration impacts on human comfort may occur, mitigation measures would be required to be implemented
  - where mitigation measures are implemented the potential for noise and vibration impacts to result in significant health impacts in the community is low to moderate,

depending on the mitigation measures implemented. Effective communication of noisy activities is important in managing such impacts on the community
    - however, it is expected that some individuals within the community may find construction noise annoying at times, even with mitigation. The management of noise impacts during construction would include a notification and complaints system.
- Operations:
    - there would be a reduction in road noise at around 2,000 sensitive receptors where the tunnel provides a bypass to the existing surface road. This reduction in noise would provide some health benefit to the community
    - there are some localised areas where an increase in noise has been predicted, particularly where there are increases in surface road traffic or close to the tunnel portals (from the operation of jet fans)
    - additional noise mitigation has been identified to minimise the impact of changes in project-related noise. Where these additional noise mitigation measures are implemented, changes in noise levels associated with the project are not expected to result in health impacts within the community that would be measurable.

Health impacts associated with changes in safety and contamination

The assessment undertaken in relation to health impacts that may as a result of the project has concluded the following:

- Safety:
    - overall, the project is expected to reduce crashes and improve pedestrian and cyclist safety through upgrades to the road and active transport network
    - the potential for project related activities to pose a risk to public safety is considered low to moderate. During construction mitigation measures would adequately address the moderate risks identified
    - during operation additional assessment would be required to adequately manage risks related to coal seam gas (methane).
- Contamination:
    - the potential for contamination (soil, water or surface water) to pose a risk to the community is considered to be low during construction and operation. It is noted that management measures have been identified to minimise the potential for contamination to impact on the community. No health impacts would be associated with the management of these materials.

Health impacts associated with other project changes

Other changes in the local environment associated with the project have the potential to result in a range of impacts on health and wellbeing of the community. The potential for changes to result in impacts on health and wellbeing is complex. Changes that may occur have the potential to result in both positive and negative impacts. Positive impacts include economic benefits, increased employment, improved access and reduced travel times and improved pedestrian and cycle access. Negative impacts may occur as a result of traffic changes during construction, property impacts and visual changes.

These impacts may reduce or increase levels of stress and anxiety within the community. In many cases the negative impacts identified are either short term (associated with construction only) and/or mitigation/management measures have been identified to minimise the potential impacts on community health. The positive impacts relate to the operation of the project, which has the potential for long-term positive health benefits to the community.

Section 1. Introduction

1.1 Project context and overview

The Great Western Highway is the key east-west road freight and transport route between Sydney and Central West New South Wales (NSW). Together, the Australian Government and the NSW Government are investing more than $4.5 billion towards upgrading the Great Western Highway between Katoomba and Lithgow (the Upgrade Program). Once upgraded, over 95 kilometres of the Great Western Highway will be two lanes in each direction between Emu Plains and Wallerawang.

The Upgrade Program comprises the following components:

- Great Western Highway Upgrade – Medlow Bath (Medlow Bath Upgrade): upgrade and duplication of the existing surface road corridor with intersection improvements and a new pedestrian bridge (approved)
- Great Western Highway East – Katoomba to Blackheath (Katoomba to Blackheath Upgrade): upgrade, duplication and widening of the existing surface road corridor, with connections to the existing Great Western Highway east of Blackheath (approved)
- Great Western Highway Upgrade Program – Little Hartley to Lithgow (West Section) (Little Hartley to Lithgow Upgrade): upgrade, duplication and widening of the existing surface road corridor, with connections to the existing Great Western Highway at Little Hartley (approved)
- Great Western Highway Blackheath to Little Hartley: construction and operation of a twin tunnel bypass of Blackheath and Mount Victoria and surface road works for tie-ins to the east and west of the tunnel (the project).

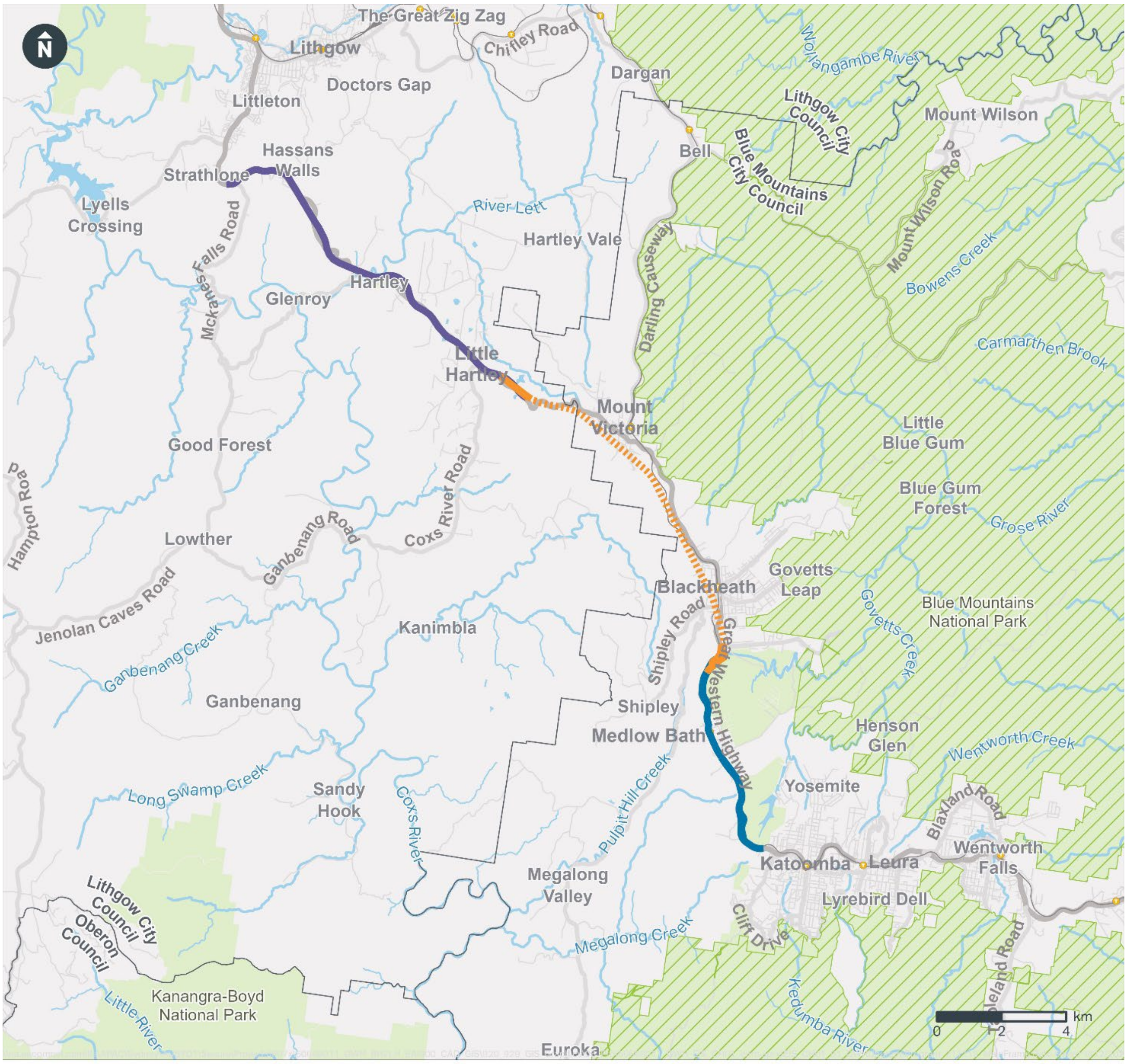
The components of the Upgrade Program are shown in Figure 1-1.

Transport for NSW (Transport) is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act) to upgrade the Great Western Highway between Blackheath and Little Hartley (the project).

The project would comprise the construction and operation of new twin tunnels around 11 kilometres in length between Blackheath and Little Hartley, and associated surface road upgrade work for tie-ins to the east and west of the proposed tunnel portals.

The project would be located around 90 kilometres northwest of the Sydney CBD and located within the Blue Mountains and Lithgow Local Government Areas (LGA).

The majority of the project would be located below ground generally along or adjacent to the west of the existing Great Western Highway between around Blackheath and Little Hartley.



Indicative only – subject to design development

Legend

Centreline
- Surface road
- Tunnel

Katoomba to Blackheath Upgrade (including Medlow Bath)
- Surface road

Little Hartley to Lithgow Upgrade
- Surface road

Existing enviroment
- Railway
- Main road
- Road
- Watercourse

- Greater Blue Mountains World Heritage Area
- National parks and reserves
- Local government area

Figure 1-1: The Great Western Highway Upgrade Program

1.2 The project

1.2.1 Key components of the project

Key components of the project are summarised in **Table 1-1** and shown in **Figure 1-2**. These components are described in more detail in Chapter 4 (Project description) of the environmental impact statement (EIS).

The indicative operational configuration of the surface road network at Blackheath and Little Hartley is shown in **Figure 1-3** and **Figure 1-4**.

Subject to approval, the project is anticipated to be open to traffic in 2030.

Table 1-1: Key components of the project

Key project component	Summary
Tunnels	Twin tunnels around 11 kilometres in length between Blackheath and Little Hartley, connecting to the upgraded Great Western Highway at both ends. Each tunnel would include two lanes of traffic and road shoulders and would range in depth from just below the surface near the tunnel portals, to up to around 200 metres underground at Mount Victoria.
Surface work	Surface road upgrade work would be required to connect the tunnels and surface road networks south of Blackheath and at Little Hartley. The twin tunnels would connect to the surface road network via: ▪ mainline carriage ways and on- and off-ramps at the Blackheath portal, located adjacent to the existing Great Western Highway and south of Evans Lookout Road ▪ mainline carriageways at the Little Hartley portal, located adjacent to the existing Great Western Highway at the base of the western escarpment below Victoria Pass and southwest of Butlers Creek.
Operational ancillary facilities	Operational infrastructure that would be provided by the project includes: ▪ a tunnel operations facility adjacent to the Blackheath portal ▪ in-tunnel ventilation systems including jet fans and ventilation ducts connecting to the ventilation facilities ▪ one of two potential options for tunnel ventilation currently being investigated, being: ○ ventilation design to support emissions via ventilation outlets ○ ventilation design to support emissions via portals ▪ water quality infrastructure including sediment and water quality basins, an onsite detention tank at Blackheath and a water treatment plant at Little Hartley ▪ fire and life safety systems, emergency evacuation and ventilation infrastructure and Closed Circuit Television ▪ lighting and signage including variable message signs and associated infrastructure such as overhead gantries.
Utilities	Key utilities required for the project would include: ▪ a new electricity substation at Little Hartley to facilitate construction and operational power supply ▪ a new pipeline between Little Hartley and Lithgow to facilitate construction and operational water supply ▪ other utility connections and modifications, including electricity substations in the tunnel
Other project elements	The project would also include: ▪ integrated urban design initiatives ▪ landscape planting.

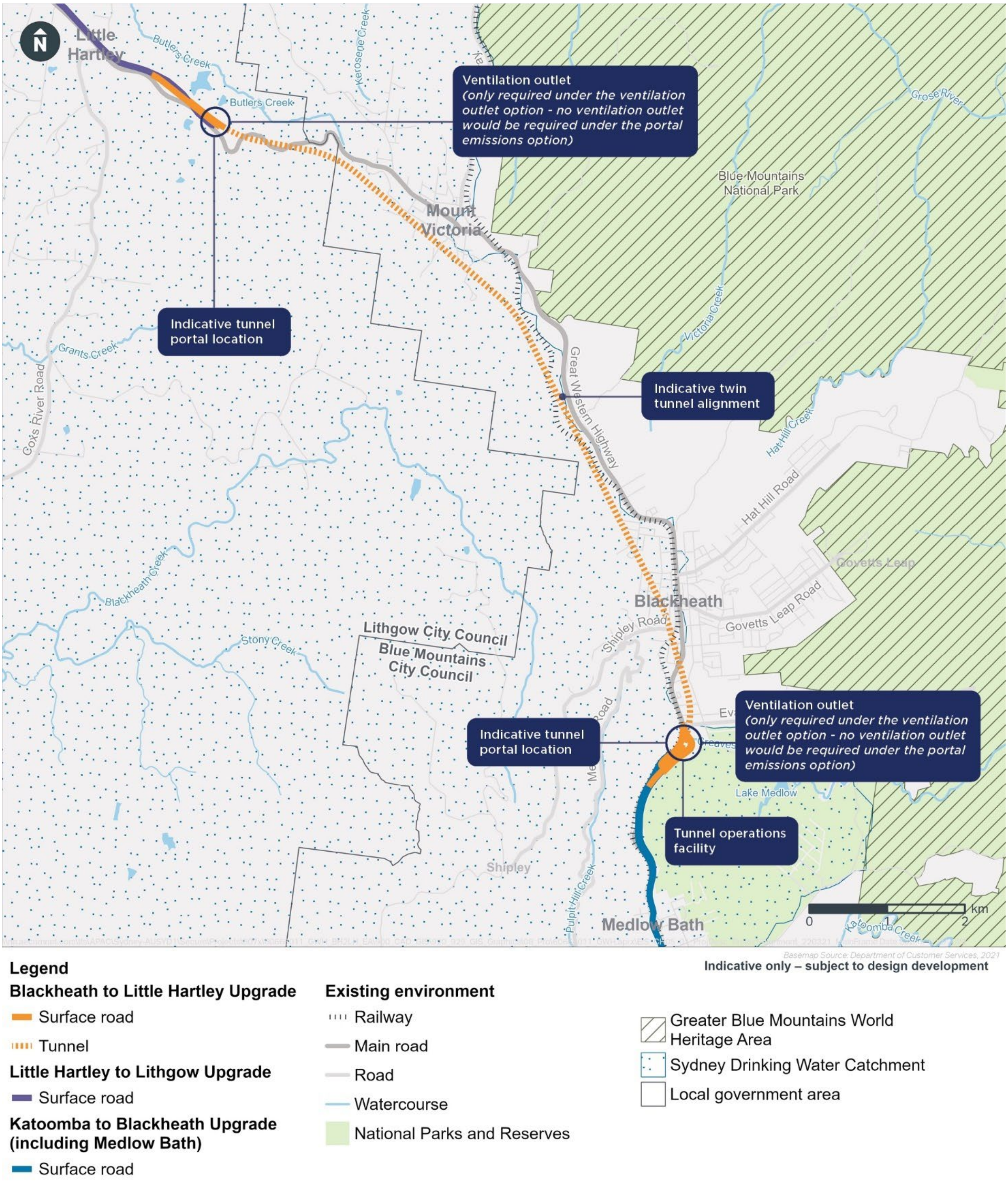


Figure 1-2: Overview of the project

Figure 1-3: Indicative operational configuration at Blackheath

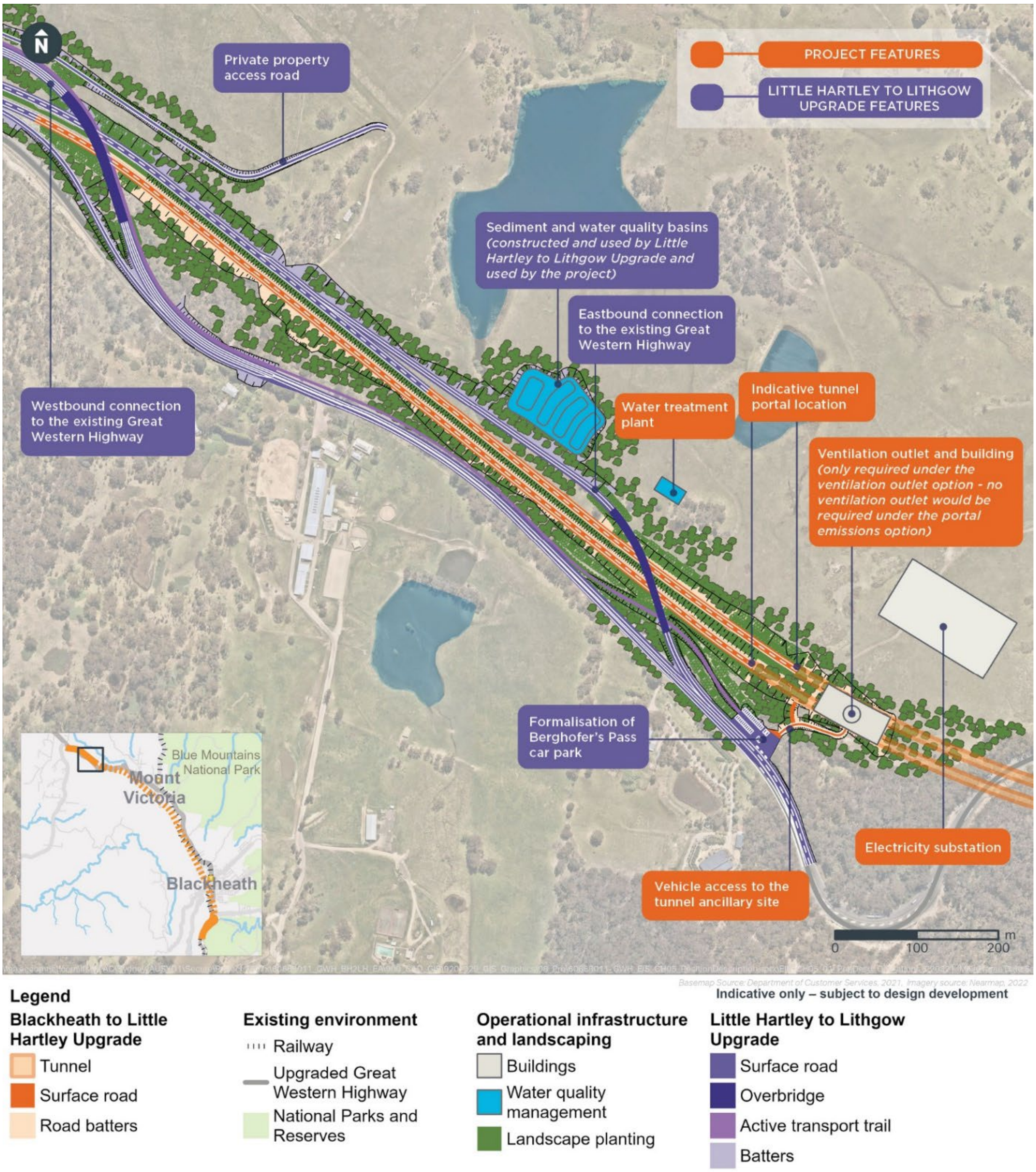


Figure 1-4: Indicative operational configuration at Little Hartley

1.2.2 Project construction

Construction of the project would include:

- site establishment and enabling works
- tunnel portal construction
- tunnelling and associated works
- surface road upgrade works
- operational infrastructure construction and fit-out, including construction of operational environmental controls
- finishing works, testing, and commissioning.

These activities are described in more detail in Chapter 5 (Construction) of the EIS.

The indicative construction footprint for the project is shown in **Figure 1-5** to **Figure 1-7**, including construction site layout and access arrangements.

Construction of the project is expected to take around eight years. Subject to planning approval, construction is planned to commence in 2024 and be completed by late 2031; however, the project would be open to traffic by 2030.

Figure 1-5: Indicative construction footprint at Blackheath

Figure 1-6: Indicative construction footprint at Soldiers Pinch

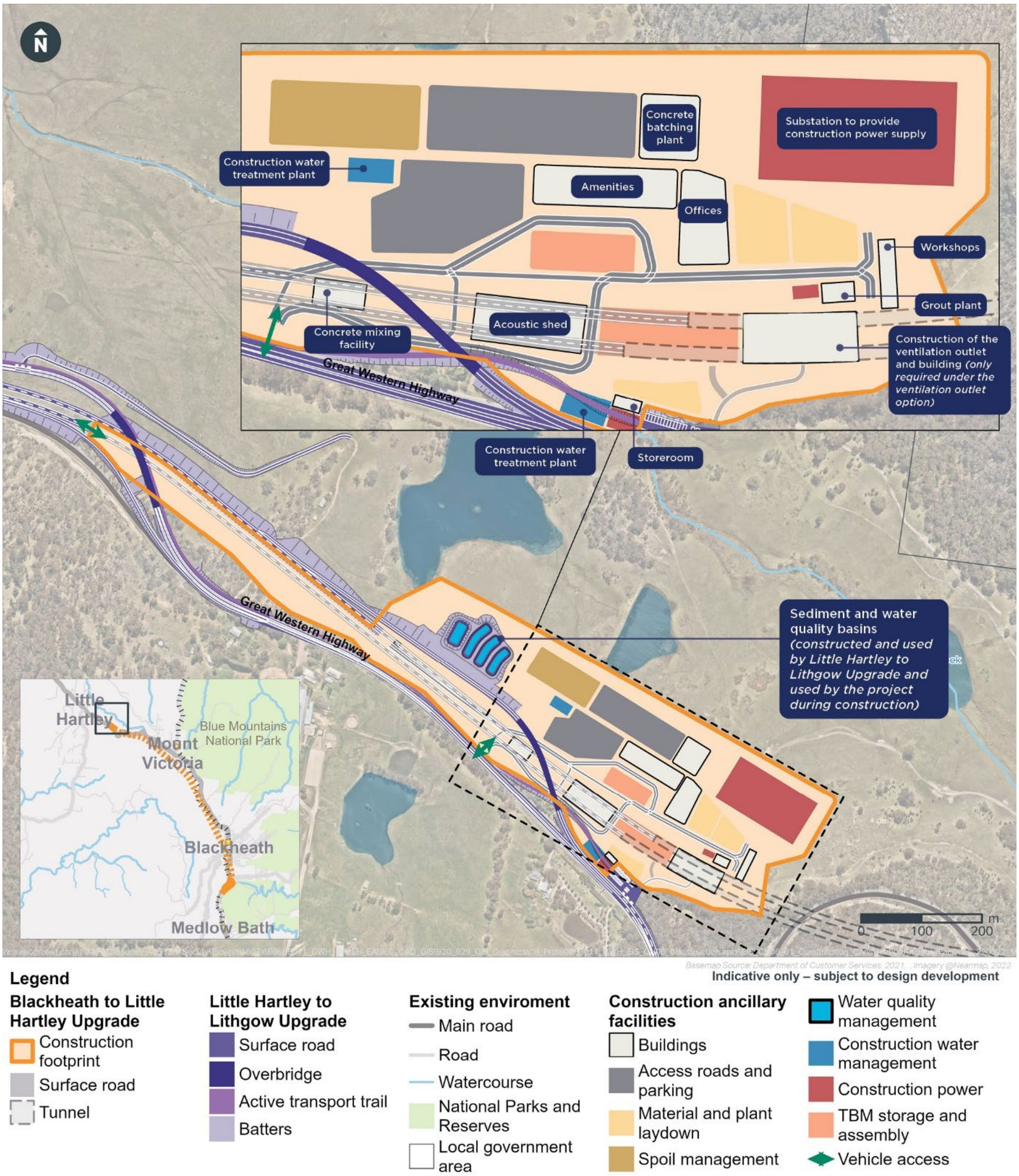


Figure 1-7: Indicative construction footprint at Little Hartley

1.2.3 Baseline environment

The Katoomba to Blackheath and Little Hartley to Lithgow Upgrades adjoining the project to the east and west respectively would be under construction when construction of the project commences (refer to Figure 1-8). To minimise environmental impacts, parts of the Katoomba to Blackheath Upgrade and Little Hartley to Lithgow Upgrade construction footprints would be used to support construction of the project.

As a result, the following activities will be undertaken at the construction sites as part of the Katoomba to Blackheath and Little Hartley to Lithgow Upgrades:

- vegetation would be cleared
- topsoil would be levelled and compacted
- site access tracks would be established
- water quality controls such as water quality and sediment basins would be installed.

The environmental impacts associated with these works have been assessed as part of the Katoomba to Blackheath Upgrade and the Little Hartley to Lithgow Upgrade.

The construction footprint for these projects are shown in **Figure 1-9** and **Figure 1-10** and form the baseline environment considered at Blackheath and Little Hartley for this EIS.

No work is proposed at Soldiers Pinch as part of the Katoomba to Blackheath Upgrade or the Little Hartley to Lithgow Upgrade and therefore the existing environment forms the baseline environment for this EIS.

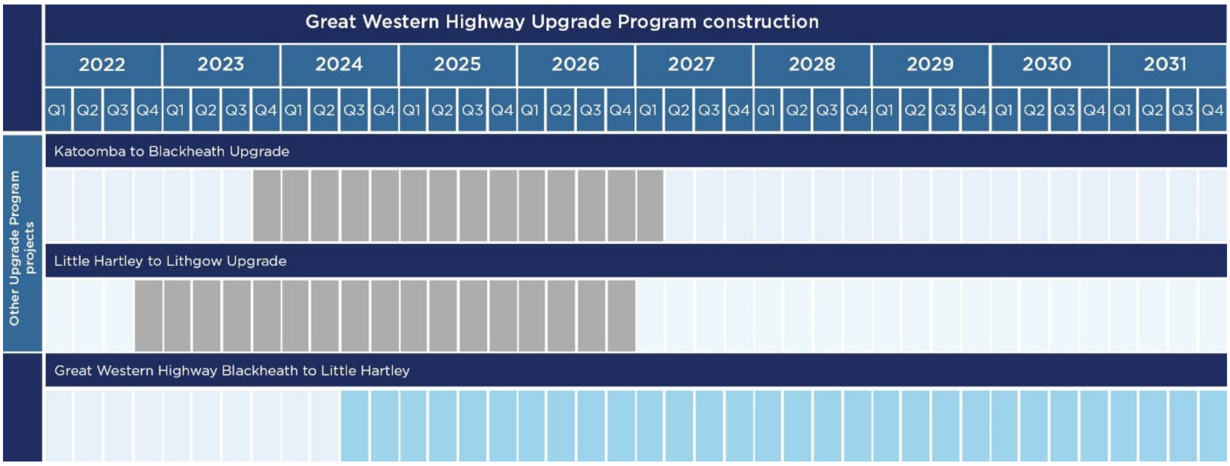


Figure 1-8: Great Western Highway Upgrade Program construction

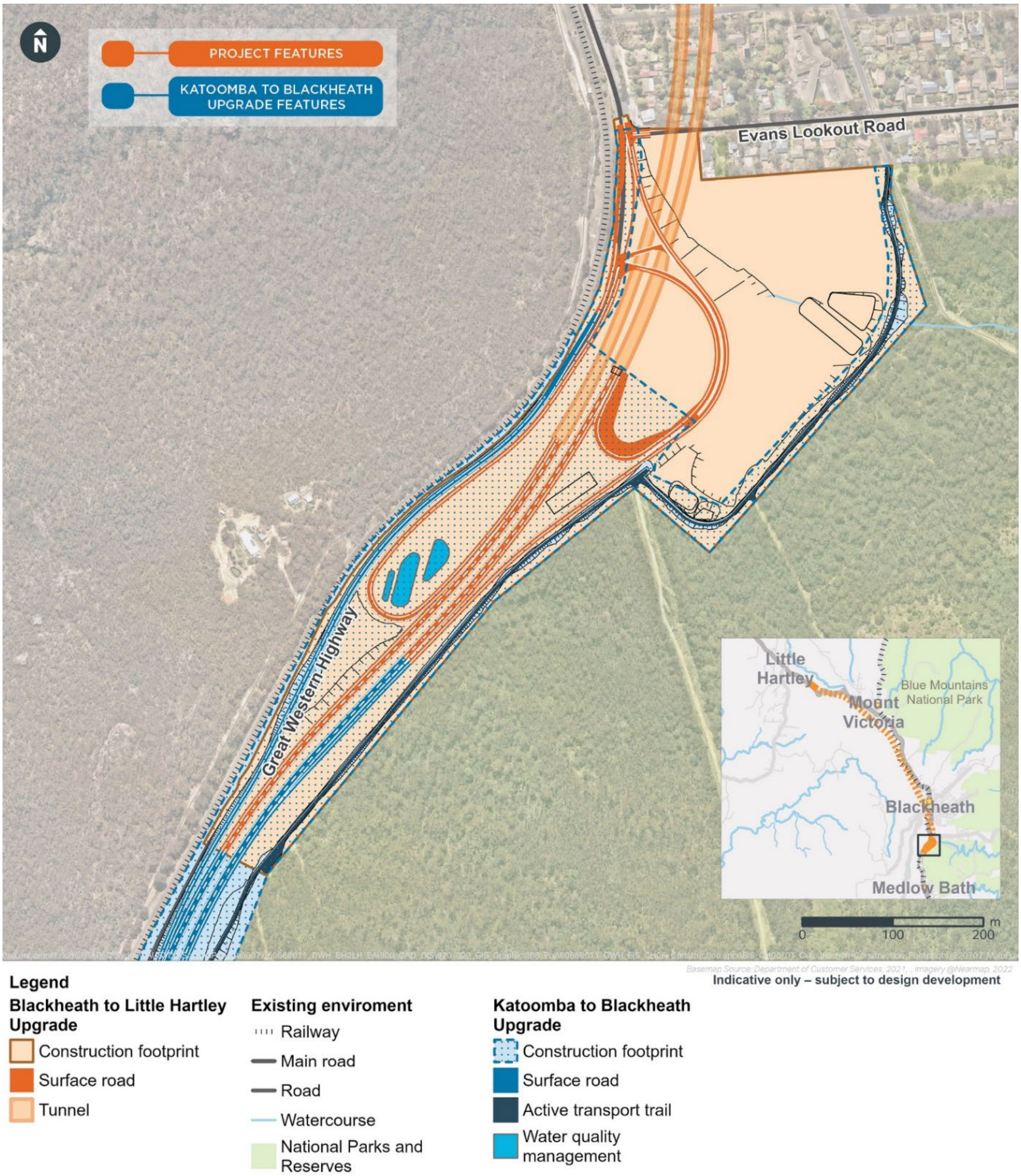


Figure 1-9: Baseline environment at Blackheath

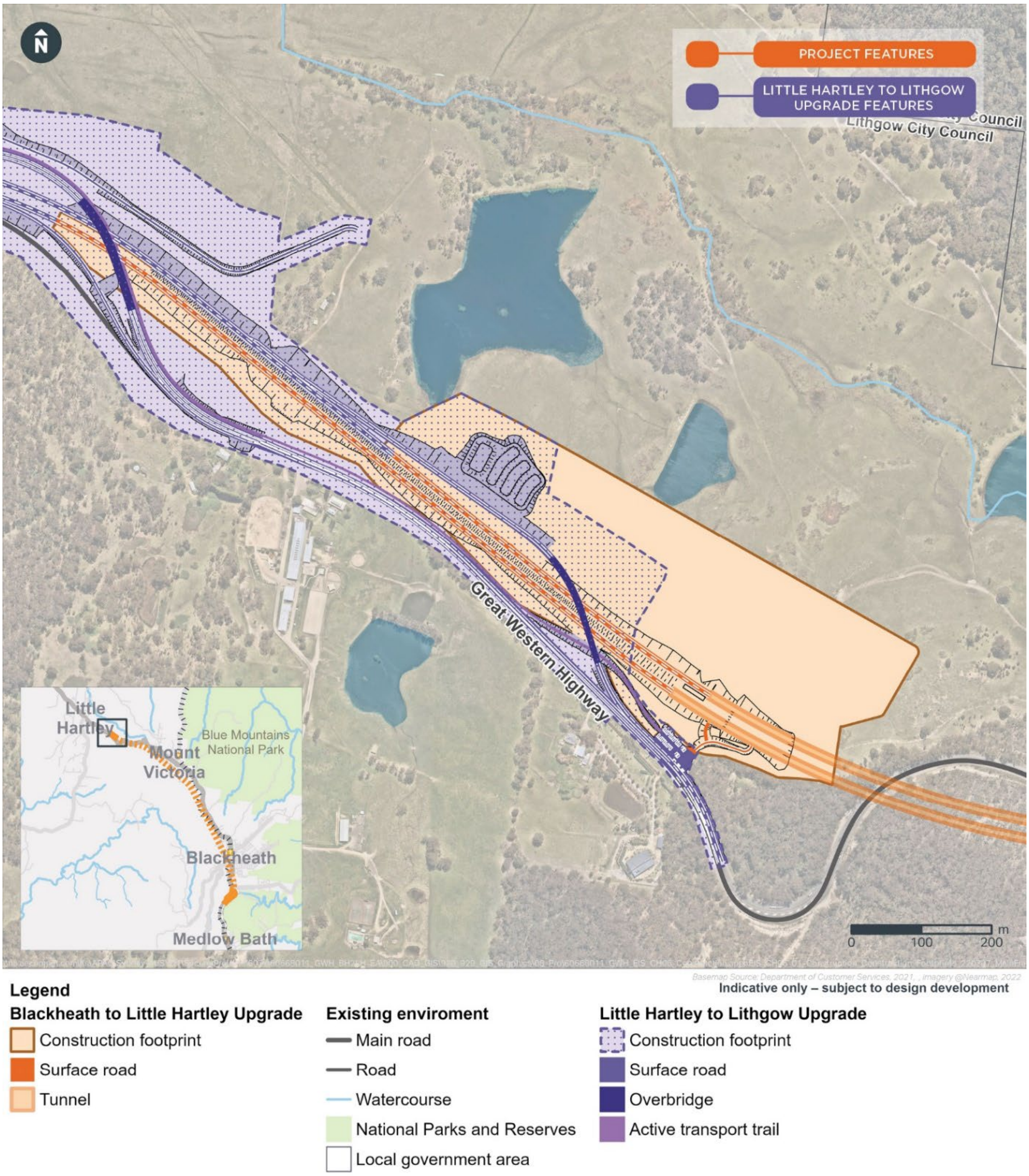


Figure 1-10: Baseline environment at Little Hartley

1.3 Purpose of this report

This human health assessment is one of a number of technical documents that form part of the EIS. The purpose of this technical report is to assess potential impacts to community health relating to air quality, noise and vibration, traffic, water and social aspects, and address the requirements outlined in **Section 1.4**. The report has been prepared in accordance with the relevant guidelines as outlined in **Section 2.3**.

This assessment has addressed impacts on community health. No assessment of impacts or risks to workers involved in the construction or operation of the Project is presented. These aspects are required to be evaluated and managed in accordance with relevant worker health and safety laws and regulations.

1.4 Assessment requirements

The Secretary's environmental assessment requirements (SEARs) issued by the NSW Department of Planning and Environment (DPE), relating to human health, and where these requirements are addressed in this report are outlined in **Table 1-2**.

Table 1-2: Secretary's environmental assessment requirements – Human health

Desired performance outcome	Secretary's requirement	Section in report where addressed
7. Health and Safety The project avoids or minimises any adverse health impacts arising from the project. The project avoids, to the greatest extent possible, risk to public safety	1. The potential **health risks** from the construction and operation of the project. The assessment must: (a) describe the current known health status of the potentially affected population	**Section 4**
	(b) describe how the design of the proposal minimises adverse health impacts and maximises health benefits	**Section 3**
	(c) assess human health risks from the operation and use of the tunnel under a range of conditions, including worst case operating conditions	**Sections 5 and 6 and 7**
	(d) human health risks and costs associated with the construction and operation of the proposal, including those associated with air quality, odours, noise and vibration (including residual noise following application of mitigation measures), construction fatigue, and social impacts (including from acquisitions) on the adjacent and surrounding areas as well as opportunity costs (such as those from social infrastructure and active transport impacts) during the construction and operation of the proposal	**Section 5.9**
	(e) include both incremental changes in exposure from existing background pollutant levels and the cumulative impacts of project specific and existing pollutant levels at the location of the most exposed receivers and other sensitive receptors (including public open space areas child care centres, schools, hospitals and aged care facilities)	**Section 5**
	(f) assess the opportunities for health improvement	**Sections 5 and 7**
	(g) assess the distribution of the health risks and benefits	**Sections 5, 7, 8 to 9**
	2. The Proponent must assess the likely risks of the construction and operation of the project on **public safety**, paying particular attention to pedestrian and cyclist safety, subsidence risks, extreme weather events, bushfire risks and the handling and use of dangerous goods.	**Section 8**

Section 2. Assessment methodology

2.1 General approach to assessing health impacts

A human health impact assessment is a systematic tool used to review key aspects of a specific project that may affect the health and wellbeing of a community. The human health impact assessment for the project has been undertaken as a desktop assessment. The term desktop assessment is used to describe that the assessment has not involved the collection of any additional data over and above that provided from project-specific EIS technical specialists, community consultations, and statistics on the existing population. Rather, the assessment has been conducted using existing information with additional detail obtained via literature review only.

Broadly, the methodology and legislative requirements to assess health impacts/risks follow a standard risk assessment and management-type approach, shown in **Figure 2-1**.

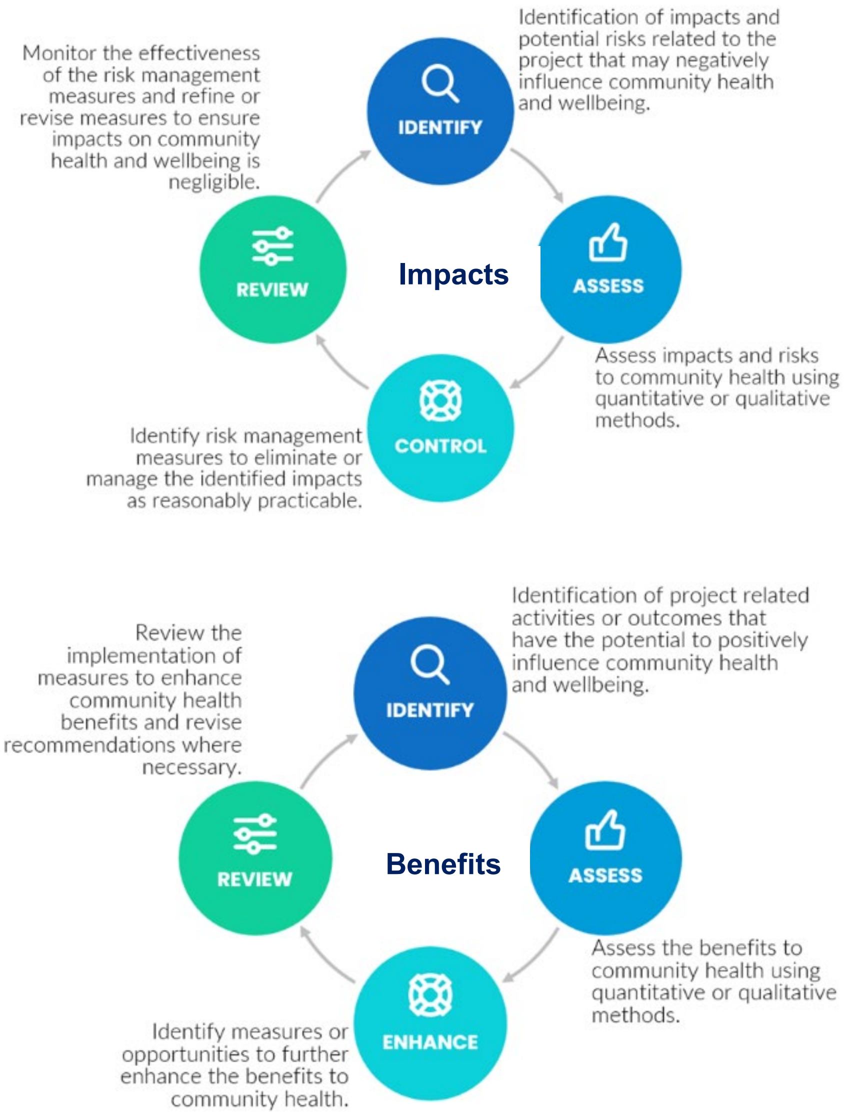


Figure 2-1: Approach to assessing human health impacts and benefits for the project

This assessment of impacts on human health has been undertaken in accordance with the guidelines, outlined in **Section 2.3**. This has involved quantitative and qualitative evaluations, drawn from other technical studies.

2.2 Defining risk

Risk assessment is used extensively in Australia and overseas to assist in decision making on the acceptability of the risks associated with the presence of contaminants or stressors in the environment and assessment of potential risks to the public. Risk is commonly defined as the chance of injury, damage, or loss. Therefore, to put oneself or the environment 'at risk' means to participate, either voluntarily or involuntarily, in an activity or activities that could lead to injury, damage, or loss.

Voluntary risks are those associated with activities that we decide to undertake such as driving a vehicle, riding a motorcycle and smoking cigarettes. Involuntary risks are those associated with activities that may happen to us without our prior consent or forewarning. Acts of nature such as being struck by lightning, fires, floods and tornados, and exposures to environmental contaminants are examples of involuntary risks.

Risks to the public and the environment are determined by direct observation or by applying mathematical models and a series of assumptions to infer risk. No matter how risks are defined or quantified, they are usually expressed as a probability of adverse effects associated with a particular activity. Risk is typically expressed as a likelihood of occurrence and/or consequence (such as negligible, low or significant) or quantified as a fraction of, or relative to, an acceptable risk number.

Risks or impacts from a range of facilities (e.g., industrial or infrastructure) are usually assessed through qualitative and/or quantitative risk assessment techniques. In general, risk or impact assessments seek to identify all relevant hazards; assess or quantify their likelihood of occurrence and the consequences associated with these events occurring; and provision of an estimate of the risk levels for people who could be exposed, including those beyond the perimeter boundary of a facility.

2.3 Guidelines for assessing health impacts

The methodology adopted for the conduct of the health impact assessment is in accordance with national and international guidance that is endorsed/accepted by Australian health and environmental authorities, and includes:

- Harris, P., Harris-Roxas, B., Harris, E. & Kemp, L., Health Impact Assessment: A Practical Guide, Centre for Health Equity Training, Research and Evaluation (CHETRE). Part of the UNSW Research Centre for Primary Health Care and Equity. University of NSW, Sydney (Harris et al. 2007)
- Health Impact Assessment Guidelines. Published by the Environmental Health Committee (enHealth), which is a subcommittee of the Australian Health Protection Committee (AHPC) (enHealth 2017)
- Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards, 2012 (enHealth 2012a)
- Schedule B8 Guideline on Community Engagement and Risk Communication, National Environment Protection (Assessment of Site Contamination) Measure, 1999 (National Environment Protection Council (NEPC 1999 amended 2013a))

- National Environmental Protection (Ambient Air Quality) Measure 2021 (NEPC 2021)
- National Environmental Protection (Air Toxics) Measure, Impact Statement for the National Environment Protection (Air Toxics) Measure, 2003 (NEPC 2003).

More specifically, in relation to the assessment of health impacts associated with exposure to nitrogen dioxide and particulate matter, guidelines available from the NEPC ((Burgers & Walsh 2002; NEPC 1998, 2002, 2003, 2009, 2010)), World Health Organization (WHO) (Ostro 2004; WHO 2003, 2006a, 2006b, 2013c) and the USEPA (USEPA 2005b, 2009a) have been used as required.

In addition, the following guidelines have been considered:

- NSW Health, Healthy Urban Development Checklist, A guide for health services when commenting on development policies, plans and proposals, 2009
- Methodology for Valuing the Health Impacts of Changes in Particle Emissions (EPA 2013)
- Air Quality in and Around Traffic Tunnels (NHMRC 2008)
- State Environmental Planning Policy (SEPP) (Resilience and Hazards) 2021 (NSW Government 2021).

2.4 Impact assessment approach

2.4.1 General

Broadly, the available guidance for the assessment of health impacts or risks, follow a standard risk assessment or risk management-type approach. This requires the identification of risk issues of concern, assessment of the potential significance of community exposures, or the benefits of the project on health outcomes, identification of measures to manage impacts or enhance benefits and review risks and benefits with the implementation of these measures.

The human health impact assessment assesses the benefits and/or impacts to the local community and users of the project.

The conduct of the human health impact assessment considers a wide range of factors with the potential to affect human health, both direct and indirect factors that affect community health and wellbeing.

To inform the assessment of potential health impacts, information on the community or population in areas surrounding the project is relevant. Information on the existing includes:

- **the community profile**, which comprises the key aspects and statistics of the population that assist in understanding the existing health and wellbeing in the community relevant to the Project. This information is presented in **Section 4**
- **existing conditions of key environments** in which the community reside that affect and are of importance for the human health impact assessment, including air quality, noise, traffic and transport, active transport, contamination and water, and other social aspects. Where relevant the existing conditions for these areas are summarised in the relevant sections of this report.

Figure 2-2 provides an overview of the key areas of interest for in the assessment of health impacts.

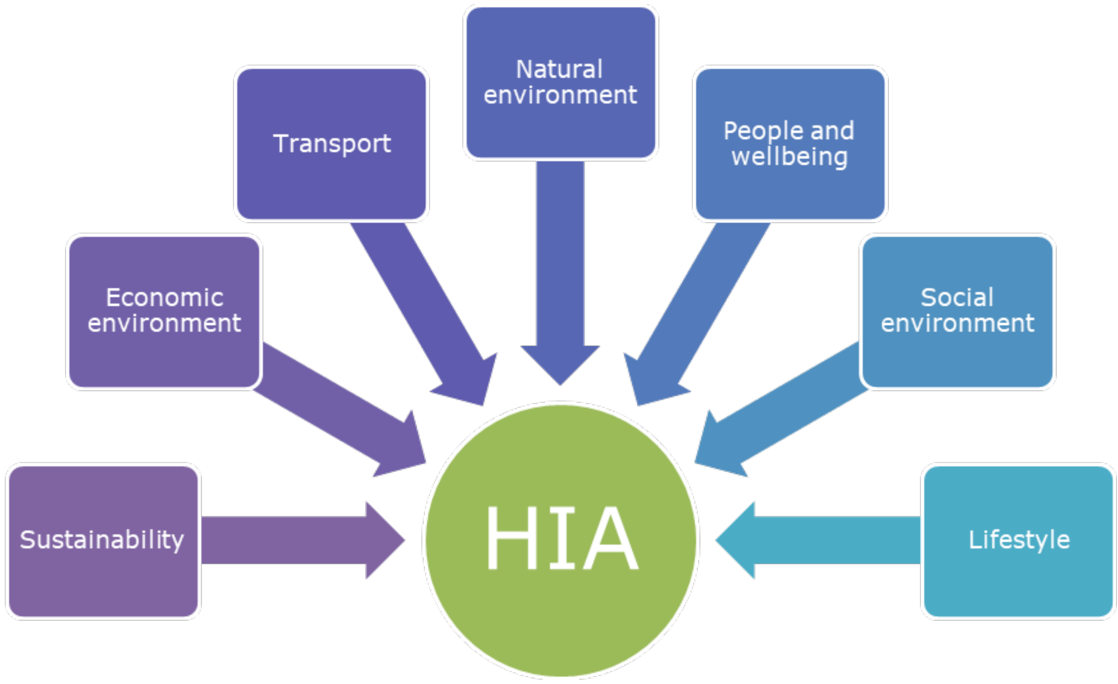


Figure 2-2: Key areas of interest for human health impact assessment (HIA)

More specifically, the scope of the human health impact assessment was determined to meet the SEARs (refer to **Section 1.4**).

The assessment has addressed impacts relevant to the following key areas (refer to each section for additional detail on the methodology relevant to the specific area).

2.4.2 Air quality

Assessment of health impacts from changes in air quality associated with the project is presented in **Section 5** along with a more detailed discussion of the methodology adopted, and the scenarios evaluated for the project. In summary, the approach adopted in the assessment has addressed the following:

- assessment of potential cumulative acute and chronic health impacts from changes in air quality particularly from nitrogen dioxide and carbon monoxide. This assessment has considered current NEPM guidance to evaluate potential health impacts and is presented in **Sections 5.7 and 5.6**
- assessment of potential incremental and cumulative acute and chronic health impacts from changes in air quality particularly from volatile organic compounds, polycyclic aromatic hydrocarbons and diesel particulate matter. This assessment has utilised current and appropriate health-based criteria for acute and chronic exposures and characterise risks in accordance with enHealth Guidelines, including a cancer risk estimate and is presented in **Section 5.5**
- evaluation of the potential cumulative and incremental health impacts from changes in air quality impacts associated with nitrogen dioxide and particulates such as $PM_{2.5}$ and PM_{10}. The assessment has utilised current and appropriate health-based criteria for acute and chronic exposures on the basis of the World Health Organisation approach. This is presented in **Sections 5.7 and 5.8**.

These assessments focused on the operational phases of the project and evaluated exposures within the tunnels and within the local community to changes in air quality associated with changes in traffic composition and movements, and from tunnel ventilation structures.

Construction impacts have been addressed on the basis of a qualitative assessment, where potential impacts and the identification of relevant management measures to minimise impacts (including nuisance[1] dust) were evaluated.

The assessment of health impacts associated with changes in air quality has relied on Appendix E (Technical report - Air Quality) of the EIS.

2.4.3 Noise and vibration

Assessment of health impacts from changes in noise and vibration associated with the project is presented in **Section 7** along with a more detailed discussion of the methodology adopted. In summary, the approach adopted in the assessment has used a qualitative approach to assessing the potential for noise and vibration impacts to adversely affect health. A qualitative approach has been adopted as the guidelines used for assessing noise and vibration impacts are protective of health. Hence the ability of the project to comply with these guidelines is the focus of the assessment presented.

The assessment considered health impacts in line with existing road traffic noise reduction policies in NSW as well as current health information and assessment guidelines available from key organisations such as the World Health Organization. The noise impact assessment considered changes in traffic composition and movements in the local areas resulting from the project.

The assessment of health impacts associated with changes in noise and vibration has relied on Appendix G (Technical report – Noise and vibration) of the EIS.

2.4.4 Contaminated land

Assessment of health impacts associated with contaminated land, as relevant to the project is presented in **Section 8.3.**

This is a qualitative assessment, providing and overview of the known presence of contamination in the project area and the potential for the community to be exposed at levels that may be of concern to community health.

The assessment also includes a qualitative evaluation of potential impacts on groundwater and surface water (in terms of community health) and any changes in flood risk for the surrounding community.

[1] Nuisance, as considered in this report relates to: nuisance dust which is dust particles that are too large to penetrate into the lungs (and result in adverse health effects) but will settle out on various surfaces and may create a visible dust layer or require cleaning; nuisance odours which are odours that are noticeable and may be considered offensive. Health effects associated with exposure to chemicals that are the cause of the odours are assessed separately.

2.4.5 Transport

Assessment of health impacts associated with changes in transport as a result of the project is presented in **Section 9.2.**

This is a qualitative assessment of impacts and benefits, and has focused on access, congestion and travel times, traffic on local roads, accidents (including pedestrian and cycle accidents) and use of non-vehicle modes of transport, which includes active transport.

2.4.6 Public safety

Assessment of health impacts associated with project-related changes that my affect public safety is presented in **Section 8.2.**

This is a qualitative review of the available information (including traffic) relevant to changes in public safety as a result of the project.

2.4.7 Social

Assessment of health impacts from changes in the social and community environment associated with the project is presented in **Section 9** along with a more detailed discussion of the methodology adopted. The focus of the assessment presented in this report relates to changes that have the potential to impact on health.

In summary, the approach adopted involves a qualitative assessment of the social characteristics which have potential to affect the health of the community (both positive and negative impacts). This assessment has considered changes in air quality, noise, traffic composition and movements, pedestrian and cycle access and safety, changes in recreational uses of the local area, changes in the connectivity (or displacement) of the community and changes in the urban environment. The assessment has drawn on published studies relating to health impacts of social changes and the social impact assessment.

The social assessment has focused on both construction and operational phases of the project, and evaluated social changes related to the project that have potential to affect the local community.

2.5 Characterising health impacts

The approach described above results in the assessment of health impacts using a combination of quantitative and qualitative approaches.

Where a quantitative assessment is undertaken, the following terminology has been used in this assessment:

- No health impacts of concern or negligible – this means that all exposure levels or concentrations quantified are below guidelines that are protective of all adverse health effects in the community or are so low that they are effectively considered to be indistinguishable from zero
- Low – exposure levels or concentrations quantified are equal to guidelines that are protective of all adverse health effects in the community or at a level that may result in some amenity impacts but no health impacts (e.g., visible dust deposition).

Where exposure levels or concentrations are not described as above, they are considered to be elevated and require management measures to be implemented to reduce exposure to a level that ensures impacts on human health are negligible to low.

Where a qualitative assessment is undertaken, the following terminology has been used in this assessment:

- No health impacts of concern or negligible – impacts evaluated or considered would not result in a health effect that would be different to the variability typically experienced within normal rural or suburban environments
- Low – impacts evaluated or considered may be noticeable or result in a short-term increase in stress and anxiety, however the level of impact can be managed through normal daily coping mechanisms just as are common when there is a change in our normal environment, e.g., new building occurs nearby, or a common travel route is required to change due to road works or closures.

Where impacts have the potential to result in the development of or exacerbation of disease or result in levels of stress and anxiety that cannot be managed through normal daily coping mechanisms, they are considered to be elevated and require management measures to be implemented to reduce exposure to a level that ensures impacts on human health are negligible to low.

2.6 Linkages to other reports

This report relies on or is informed by the technical reports identified in **Table 2-1**. The health impact assessment has drawn on information provided in these reports and, in some areas, provides a summary of key (and relevant) aspects. All details relevant to the underlying assumptions, methodology and interpretation of impacts relevant to these specialist areas are presented in the individual reports. Where more detail than provided in the health impact assessment is required, the relevant technical report should be reviewed.

Table 2-1: Linkages to other technical reports appended to the EIS (to be revised once reports are available)

Technical report in EIS	Relevance to health impact assessment
Appendix D (Technical report – Transport and traffic)	Provides an assessment of the project's effects on the transport network within the project area. Information related to changes in traffic volumes, routes, travel times, road safety and pedestrian and cyclist safety.
Appendix E (Technical report - Air quality)	Provides an assessment of the project's effects on local air quality within the project area. Findings from the report have informed the assessment of health impacts from changes in air quality as a result of the project. The Stacey Agnew (2021) Ventilation Options Report, which is an attachment to the Air quality report provides an assessment of in-tunnel air quality, which is relevant to the assessment of impacts for users of the project, once complete,
Appendix G (Technical report – Noise and vibration)	Provides an assessment of the project's potential noise and vibration impacts on sensitive receptors within the project area. Findings from the report have informed the assessment of health impacts from changes in noise and vibration (from surface works and tunnelling).
Appendix P (Technical report – Economics and business)	Provides an assessment of the project's impact on businesses Findings from the report have informed the assessment of health issues related to impacts on businesses in the project area.
Appendix I (Technical report – Groundwater) Appendix J (Technical report - Surface water and flooding)	Provides an assessment of the project's impact on surface water and groundwater quantity and quality. Findings have informed the assessment of impacts on water availability and quality, in relation to health.
Chapter 22 of the EIS – Hazards and risk	Provides an assessment of hazards relevant to the project, in particular bushfire hazards and dangerous goods.
Appendix O (Technical report – Social)	Provides an assessment of the project's impact on social cohesion and amenity. Findings have informed the assessment of impacts on amenity and social changes within the community.
Appendix K (Technical report – Contamination)	Provides an assessment of contamination and soil issues relevant to the construction of the project. Findings have informed the assessment of potential impacts of contamination on the community during construction.

2.7 Features of the risk assessment

The health impact assessment has been carried out in accordance with international best practice and general principles and methodology accepted in Australia by groups/organisations such as National Health and Medical Research Committee (NHMRC), NEPC and enHealth. There are certain features of risk assessment methodology that are fundamental to the assessment of the outputs and to drawing conclusions on the significance of the results. These are summarised below:

- the assessment has relied on assessments completed in other technical reports, specifically in relation to traffic, air quality, noise and vibration, contamination, water, economic and social impacts
- a risk assessment is a systematic tool that addresses potential exposure pathways based on an understanding of the nature and extent of the impact assessed and the uses of the local area by the general public. The risk assessment is based on an estimation of maximum, or worst case, impacts (air quality, noise and vibration) in the local community and hence is expected to overestimate the actual risks

- conclusions can only be drawn with respect to project related impacts as outlined in the respective technical reports
- available statistics in relation to the existing health status of the existing community are presented. However, the health impact assessment does not provide an evaluation of the overall health status of the community or any individuals. Rather, it is a logical process of calculating and comparing potential exposure concentrations (acute and chronic) in surrounding areas (associated with the project) with regulatory and published acceptable air pollutant concentrations that any person may be exposed to over a lifetime without unacceptable risk to their health. It can also involve calculating an incremental impact that can be evaluated in terms of an acceptable level of risk.

2.8 Limitations and considerations

There are certain features of health impact assessment methodology important to acknowledge in the development of any assessment. These relate to the limitations of the methodology and the constraints applied within the health impact assessment to ensure a focus on aspects that can be influenced as part of the project. These are summarised below (also refer to **Section 11** for discussion of uncertainties):

- a health impact assessment is a systematic tool used to review key aspects of a specific project that may affect the health of the local community. The assessment includes both qualitative and quantitative assessment methods
- a health impact assessment involves a number of aspects where a qualitative assessment is required to be undertaken. Where this is undertaken, it provides a general indication of potential benefits or impacts only
- the community evaluated in a health impact assessment is limited by the extent of the studies undertaken in informing an EIS. It is not possible to evaluate impacts on the health of the community outside these areas
- a health impact assessment relies on data provided from other studies prepared for an EIS (as listed for this project in **Table 2-1**). The conclusions of this health impact assessment, therefore, depends on the assumptions and calculations undertaken to generate the data from these other studies utilised in this assessment
- conclusions can only be drawn with respect to impacts related to a project as outlined in an EIS. Other health issues, not related to the project, that may be of significance to the local community are not addressed in the health impact assessment
- the health impact assessment for this project did not address occupational health for construction workers or workers involved in the operation of the project
- the health impact assessment reflects the current state of knowledge regarding the potential health effects of identified chemicals and pollutants for this project. This knowledge base may change as more insight into biological processes is gained, further studies are undertaken, and more detailed and critical review of information is conducted.

Section 3. Incorporation of health issues into the project design

The design of the project has been developed through an iterative approach, with considerations given to minimising impacts on community health and wellbeing, as detailed in Chapter 4 of the EIS – Project alternatives and options. Some of the key design considerations that have been incorporated into the project that have minimised impacts to community health include:

- use of tunnel boring machines (TBMs), and the use of two TBMs rather than four, which would minimise the construction footprint, tunnel spoil haulage through Blackheath and Mount Victoria and construction duration, which minimises the duration of potential construction impacts on the community health and wellbeing
- optimising the construction methodology to minimise the construction footprint and number of construction sites, which minimises the number of locations and extent of impacts during construction that may impact on community health and wellbeing. This includes minimising impacts from construction dust, construction noise, the use of some existing recreational areas (including Browntown Oval) which would displace existing active and passive recreational facilities or disturbance of contamination (including asbestos) at the old Blackheath tip site.
- minimising the acquisition of residential properties for the project which provides a benefit to the health and wellbeing of residents located close to the project. Minimising property acquisitions and the need for established residents to move home has the potential to minimise increases stress and anxiety
- tunnel alignment to achieve a shorter and straighter tunnel, which minimises emissions from vehicles using the tunnel and improves driver safety in the tunnel
- physical separation of the tunnel portals which minimise the cumulative impact on air quality of tunnel portal emissions should this ventilation option be preferred, and provides space for tunnel ventilation outlets to be constructed should this ventilation option be the preferred
- operation of the tunnel reduces traffic on surface roads, which would improve existing air quality and noise impacts for the community located adjacent to the surface road

In addition, the tunnel ventilation system has been designed to meet the in-tunnel air quality criteria, and to ensure emissions are dispersed so that there are minimal effects on air quality. For the ventilation outlet scenario, the design considerations included ensuring the location, height, diameter and emission ventilation rate minimises local air quality impacts.

Refer to Chapter 4 (Project alternatives and options) of the EIS for additional details on design considerations.

Section 4. Community profile

4.1 General

This section summarises the demographics and existing health of the community potentially impacted by the project. While the key focus of the assessment was the local community surrounding the project, some aspects of the assessment required consideration of statistics derived from larger populations, such as those within larger Local Government Areas (LGAs), Greater Sydney and NSW.

Information has been obtained from the Australian Bureau of Statistics (ABS) Census 2021, information relevant to LGAs and health districts (in particular the Nepean Blue Mountains Local Health District). In some cases, where local data is lacking, information has been obtained (or compared with) data from larger population areas of Greater Sydney and/or NSW.

4.2 Study area

The study area, illustrated in **Figure 4-1**, identifies the area over which impacts to human health have been considered. It is noted that the specific populations evaluated for various impacts include sub-populations or sub-areas within this broader study area. In relation to the location of sensitive receptors or receivers, **Figure 4-1** shows the location of community, education and medical facilities as well as parks and recreational areas (noting the national parks are also considered recreational areas). More specific detail on the location of all sensitive receivers is provided in **Section 4.3**. Where relevant, smaller sub-areas relevant to other technical assessments are defined and discussed further in the relevant sections of this report.

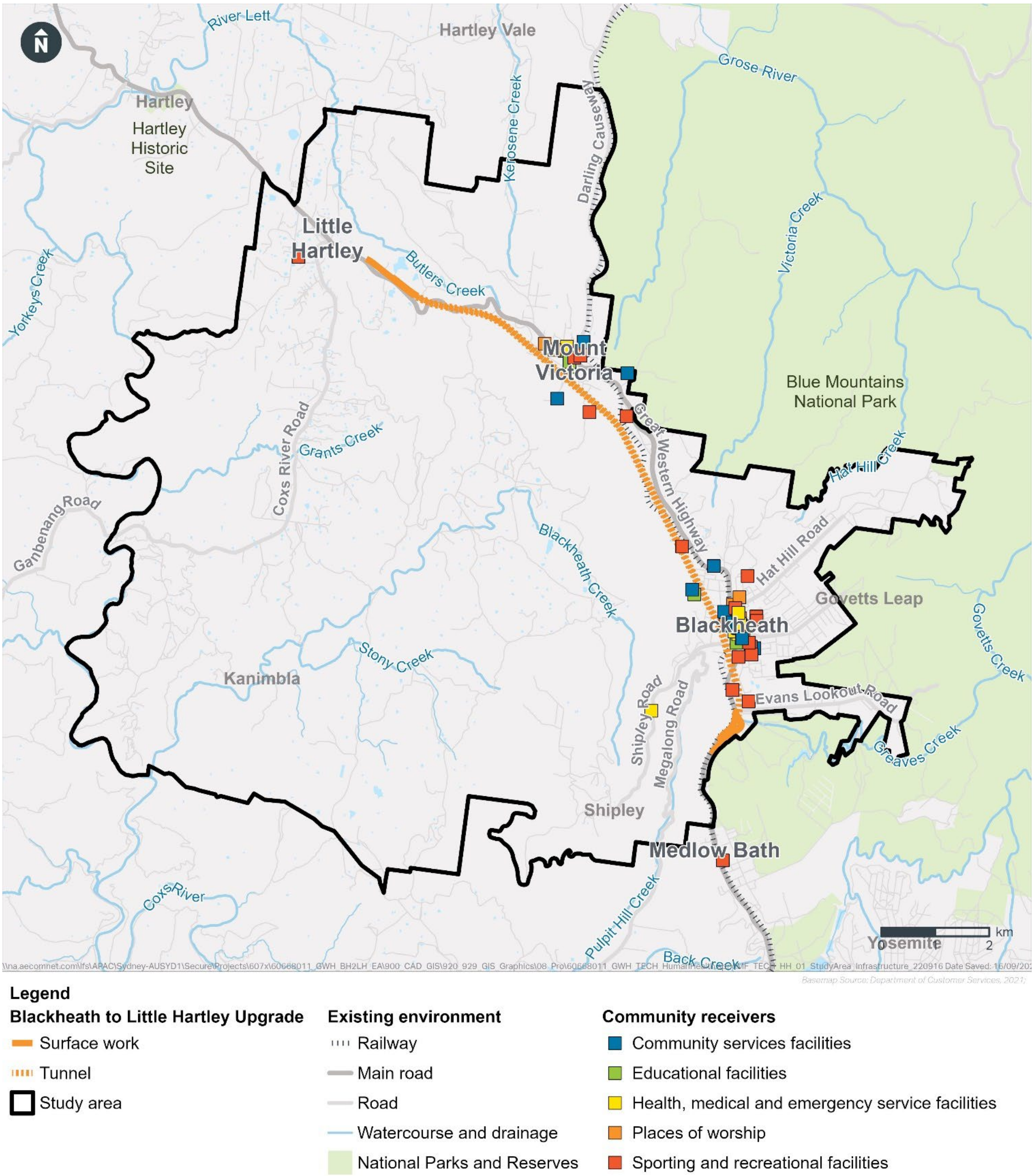


Figure 4-1 Human health impact assessment study area

4.3 Sensitive receptors and potentially impacted communities

The potentially impacted communities considered in the assessment include those who live or work within the vicinity of the construction sites, tunnel portals (where the preferred ventilation option), ventilation outlets (where the preferred ventilation option) and road surface upgrades associated with the project.

This includes community receptors or receivers including hospitals, child-care facilities, schools and aged care facilities, and sensitive receivers such as residential, workplace and recreational receivers. The assessment of noise impacts also identified places of worship and community areas as sensitive receivers.

Figure 4-2 and **Figure 4-3** show the location of sensitive residential areas considered in the assessment of air quality impacts and noise impacts (where noise catchment areas are defined).

Key receivers identified in the study area are listed in **Table 4-1**. These receptors are those specified in Appendix G (Technical report – Noise and vibration) of the EIS and are included in the sensitive receptors illustrated in **Figure 4-2.**

Table 4-1 Key sensitive receptors included in the human health impact assessment

Receiver	Type
Blue Gum Montessori Children's house	Childcare centre
Possum's Patch Child Care Centre	Childcare centre
Mount Victoria Public School	Education
Blackheath Public School	Education
Mountains Christian College	Education
OneSchool Global	Education
Blackheath Uniting Church	Place of worship
Blackheath Presbyterian Church	Place of worship
Blackheath Baptist Church	Place of worship
St Aidan's Anglican Church	Place of worship
Sacred Heart Catholic Church	Place of worship
Saint Peter's Catholic Church	Place of worship
St Pauls' Catholic Church	Place of worship
Sutton Park	Active recreation
Whitley Park	Active recreation
Neate Park	Active recreation
Blackheath Memorial Park	Active recreation
Rotunda park	Active recreation
Mount Victoria Memorial Park	Active recreation
Fairy Bower Reserve	Active recreation
Blackheath Cemetery	Passive recreation
Blackheath Area Neighbourhood Centre	Community

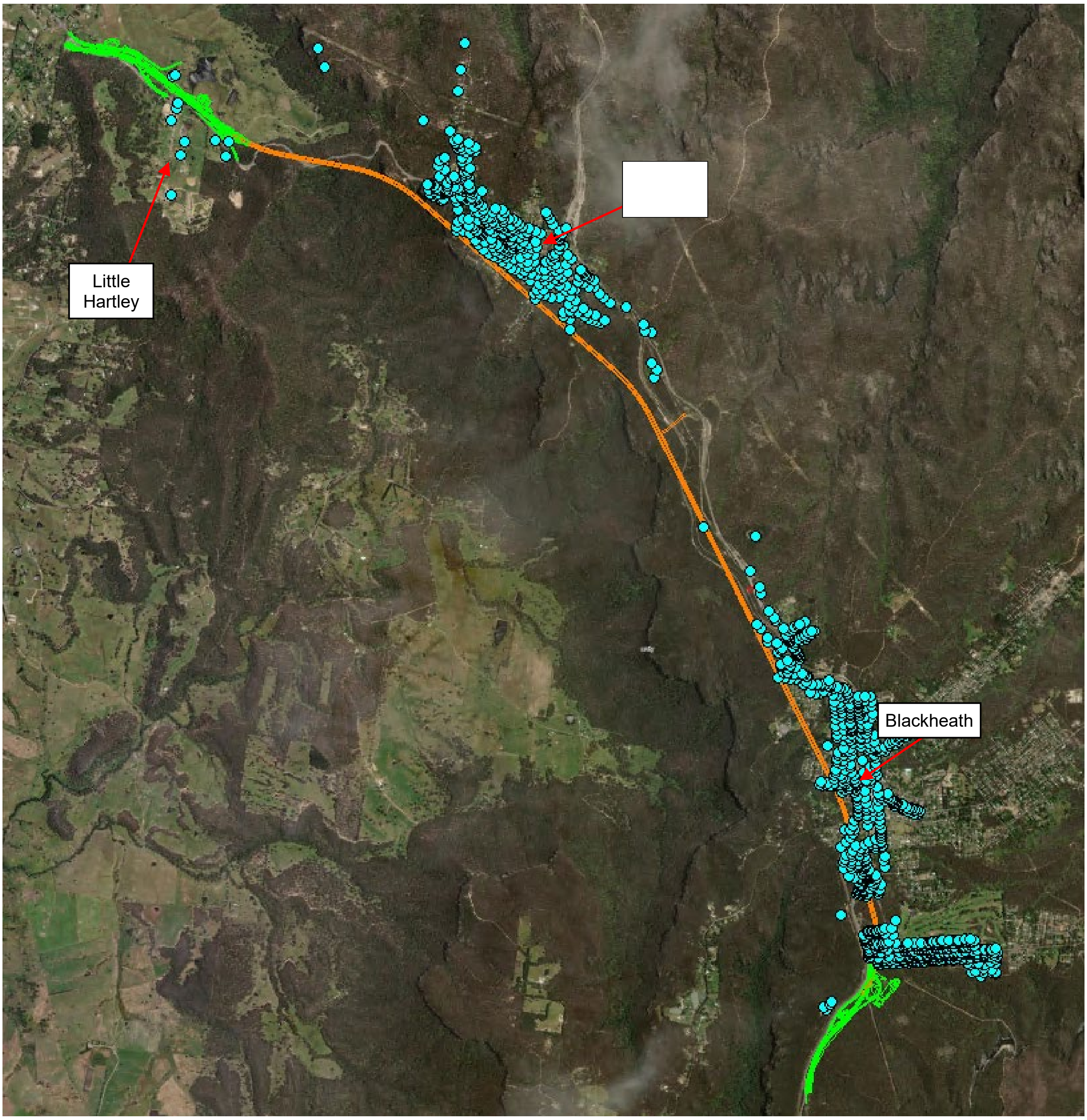


Figure 4-2: Location of sensitive receptors in the study area as relevant to evaluating air quality impacts

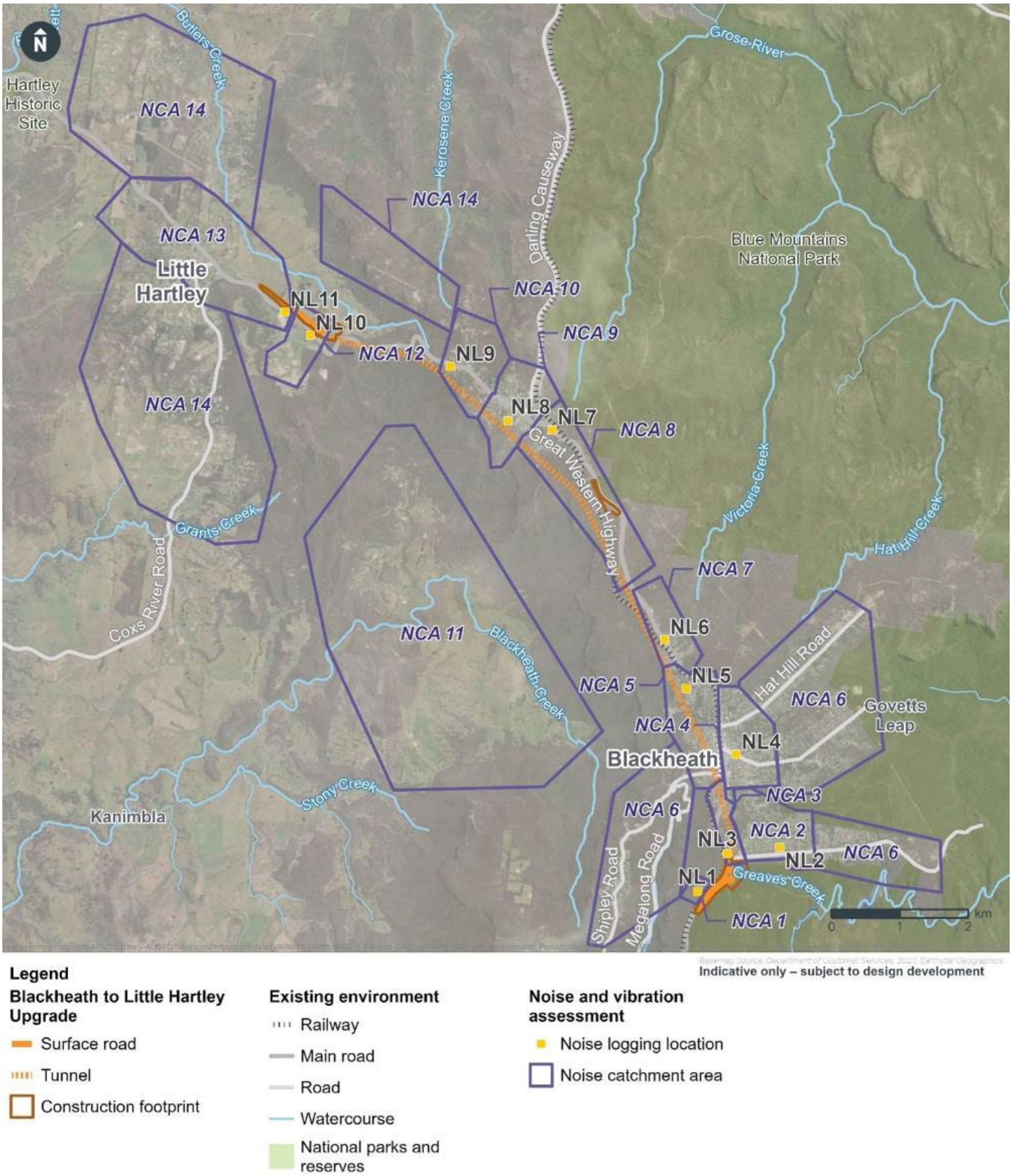


Figure 4-3: Location of noise catchment areas, where sensitive receptors are located in relation to evaluating noise impacts

4.4 Population profile

The population within the study area consists of residents and workers as well as those attending schools, day care centres, hospitals and recreational areas. The composition of the populations located within the study area is expected to be generally consistent with population statistics for the larger individual suburbs that are wholly or partially included in the study area. Population statistics for the suburbs in the vicinity of the proposed portals and ventilation facilities as well as the LGAs are available from the ABS for the census year 2021 and are summarised in **Table 4-2**. For the purpose of comparison, the population statistics presented also include the statistics for the larger statistical areas of Greater Sydney and the rest of the NSW (excluding Greater Sydney) (as defined by the ABS).

Table 4-3 presents a summary of a selected range of demographic measures relevant to the population of interest with comparison to statistical areas of Greater Sydney and the rest of NSW (excluding Greater Sydney).

Table 4-2: Summary of population statistics in study area

Location	Total population		% Population by key age groups					
	Male	**Female**	**0–4**	**5–19**	**20–64**	**65+***	**1–14***	**30+***
Suburbs								
Medlow Bath	286	281	2	11	57	28	14	73
Blackheath	2,223	2,446	3	15	53	29	17	77
Mount Victoria	483	455	5	14	54	25	17	71
Kanimbla	91	89	3	13	55	25	12	74
Little Hartley	319	307	4	15	61	22	18	73
Local government areas								
Blue Mountains	37,865	40,258	5	18	54	22	23	68
Lithgow	10,529	10,313	5	17	54	25	21	68
Statistical areas of Sydney and NSW								
Greater Sydney	2,585,238	2,645,912	6	18	61	15	23	62
Rest of NSW (excluding Greater Sydney)	1,392,556	1,437,081	5	18	54	22	23	65

Ref: Australian Bureau of Statistics, Census Data 2021

SA = statistical area

* Age groups specifically relevant to the characterisation of risk

Table 4-3: Selected demographics of population of interest

Location	Median age	Median household income ($/week)	Median mortgage repayment ($/month)	Median rent ($/week)	Average household size (persons)	Unemployment rate (%)*	Socioeconomic disadvantage (IRSD)***
Suburbs							
Medlow Bath	52	1,312	1,559	398	2.1	4.2**	3
Blackheath	53	1,332	1,733	380	2.0		3
Mount Victoria	49	1,197	1,625	380	2.1		2
Kanimbla	54	1,625	2,400	275	2.3	2.0**	5
Little Hartley	49	1,843	1,733	390	2.6		5
Local government areas							
Blue Mountains	45	1,756	2,035	400	2.4	3.1	5
Lithgow	46	1,196	1,500	270	2.3	5.3	1
Statistical areas of Sydney and NSW							
Greater Sydney	37	2,077	2,427	470	2.7	4.7	--
Rest of NSW (excluding Greater Sydney)	43	1,434	1,733	330	2.4	--	--

Source: Australian Bureau of Statistics, Census Data 2021

* Unemployment rates available for March quarter 2022 for smaller population from https://www.nationalskillscommission.gov.au/topics/small-area-labour-markets

** Data for Blackheath - Megalong Valley (which includes Mount Victoria) and Lithgow region (which includes Kanimbla and Little Hartley) – SA2 statistical areas

*** Index of Relative Socioeconomic Disadvantage (IRSD) available for the 2016 census period (data for 2021 not published at the time this report was prepared). IRSD quartile values presented where a value of 1 is the most disadvantaged and 5 is least disadvantaged when compared with the population of NSW. The key aspects considered in the index include income, qualifications, skills, unemployment, disability and language (speaking English well)

Comparing the populations of the study area to that of Greater Sydney the following is noted:

- the population in the smaller suburbs generally comprise an older population, with a smaller proportion of young children and higher proportion of individuals aged 30 and over and 65 and over, and a smaller household size (with the exception of Little Hartley)
- the population in the larger areas of the Blue Mountains and Lithgow LGAs are more similar to Greater Sydney noting the median age and household size is more consistent with the rest of NSW than Greater Sydney
- the social demographics of an area have some influence on the health of the existing population. As shown in **Table 4-3** the population in the study area generally has lower levels of unemployment, lower levels of household income and lower levels of mortgage repayments and rents than Greater Sydney
- in relation to the potential for socioeconomic disadvantage, most suburbs within the study area are considered average or less disadvantaged. The population of Mount Victoria as an IRSD ranking of 2 indicating the population may be more disadvantaged, principally as a result of more households with lower incomes, or more people with no qualifications or with few skills. This may mean the population of Mount Victoria may be more vulnerable (in terms of health impacts) to changes that impact on employment.

4.5 Existing health of population

4.5.1 General

The assessment presented in this report has focused on key pollutants that are associated with construction and combustion sources (from vehicles), including volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO), nitrogen dioxide (NO_2) and particulate matter (PM) (namely $PM_{2.5}$ and PM_{10}). For these pollutants, there are a large number of sources in the study area including other combustion sources (wood-fired heating, domestic cooking, industrial emissions) and non-combustion sources including other local construction/earthworks. Other aspects that affect the health of an individual include personal exposures (such as smoking) and risk taking behaviours.

When considering the health of a local community there are many factors to consider. The health of the community is influenced by a complex range of interacting factors including age, socio-economic status, social networks, behaviours, beliefs and lifestyle, life experiences, country of origin, genetic predisposition and access to health and social care. While it is possible to review existing health statistics for the local areas surrounding the project and compare them to the Greater Sydney area and NSW, it is not possible or appropriate to be able to identify a causal source, particularly individual or localised sources.

Information relevant to the health of populations in NSW is available from NSW Health for populations grouped by local health districts (where the study area is located in the Nepean Blue Mountains Local Health District).

Most of the health indicators presented in this report are not available for each of the smaller suburbs/statistical areas surrounding the site. Health indicators are only available from a mix of larger areas (that incorporate the study area), namely the Nepean Blue Mountains Local Health District. There are few health statistics that are reported for the local government areas relevant to this project. The health statistics for these larger areas (and in some cases data for the Greater Sydney area) are assumed to be representative of the smaller population located within these districts and areas.

4.5.2 Health related behaviours

Information in relation to health related behaviours (that are linked to poorer health status and chronic disease including cardiovascular and respiratory diseases, cancer, and other conditions that account for much of the burden of morbidity and mortality in later life) is available for the larger populations within the local health districts in Sydney and NSW. The study population is largely located within the Nepean Blue Mountains Local Health District. The incidence of these health-related behaviours in these districts, compared with other districts in NSW, and the state of NSW (based on NSW Health data from 2020 and 2021) is illustrated in **Figure 4-4**.

Review of this data indicates the population in the Nepean Blue Mountains local health district (that includes the study area) has higher rates of smoking and alcohol consumption, lower intake of recommended serves of fruit, higher rates of people who are overweight or obese compared with NSW.

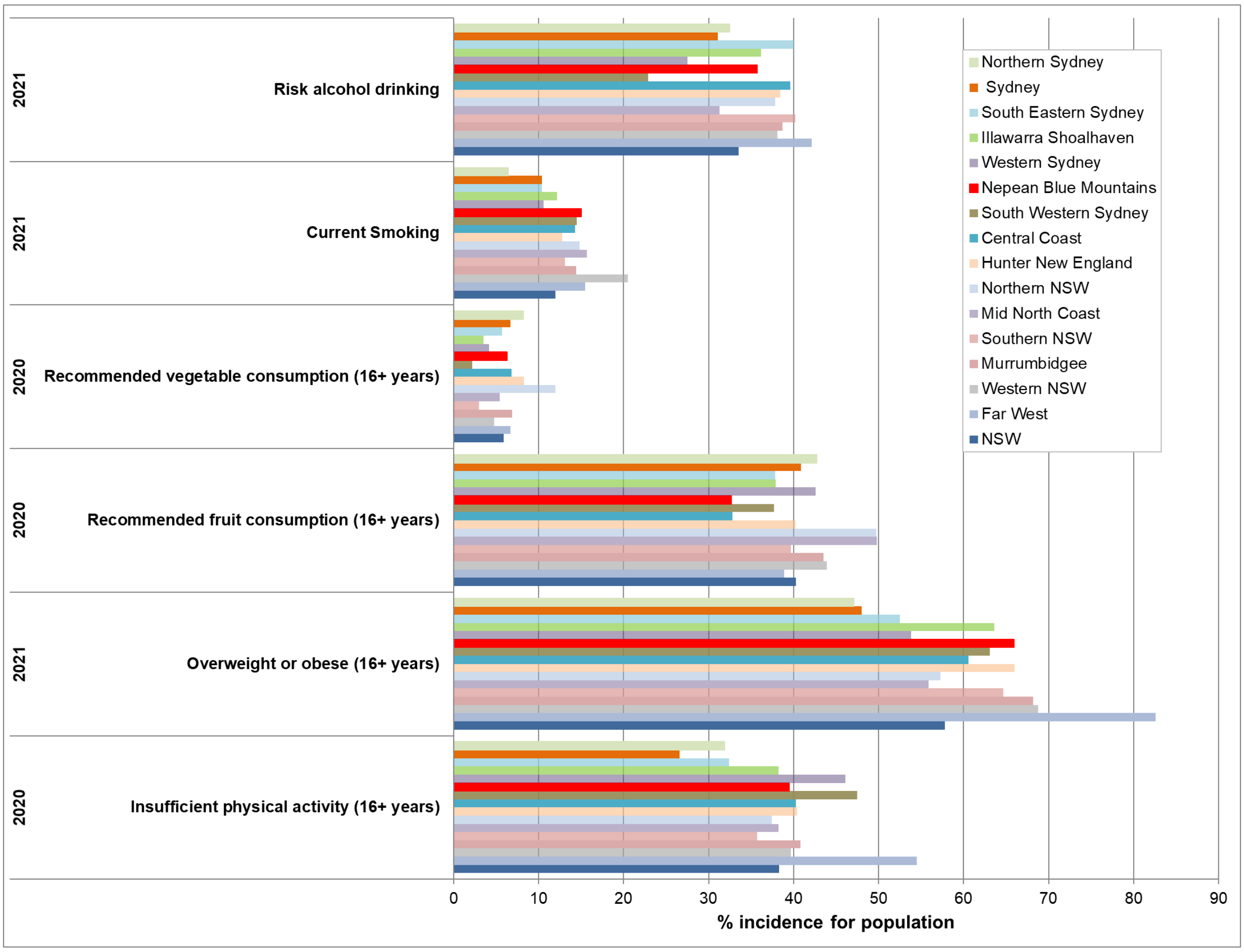


Figure 4-4: Summary of incidence of health-related behaviours (Source: HealthStats NSW, 2022)

Note: these health related behaviours include those where the behaviour/factor may adversely affect health (eg alcohol drinking, smoking, being overweight/obese and inadequate physical activity) and others where the behaviour/factor may positively affect (enhance) health (eg adequate fruit and vegetable consumption).

The study area is located in the Nepean Blue Mountains Local Health District (red bars).

4.5.3 Health indicators

Figure 4-5 presents a comparison of the rates of the key mortality indicators based on data from 2017 to 2019 (depending on the available data) for all causes, potentially avoidable, cardiovascular disease, respiratory disease (all causes) and chronic obstructive pulmonary disease (COPD), reported in the Nepean Blue Mountains Local Health District, with comparison to other NSW local health districts (in urban and regional areas) as well as NSW as a whole.

Figure 4-6 presents a comparison of the rates of the hospitalisations for key health effects based on data from 2019-2020 for cardiovascular disease, respiratory disease, asthma (5 to 34 years) and COPD (65+ years) reported in the Nepean Blue Mountains Local Health District, with comparison to other NSW local health districts (in urban and regional areas) as well as NSW as a whole.

It is noted that the data reported in these figures are based on statistics that are publicly available from NSW Health. Therefore, some of the statistics for mortality and hospitalisations relate to slightly different health endpoints and/or different age groups. The statistics are included for general comparison and discussion. Actual health statistics considered in the characterisation of risk are presented in **Table 4-4**.

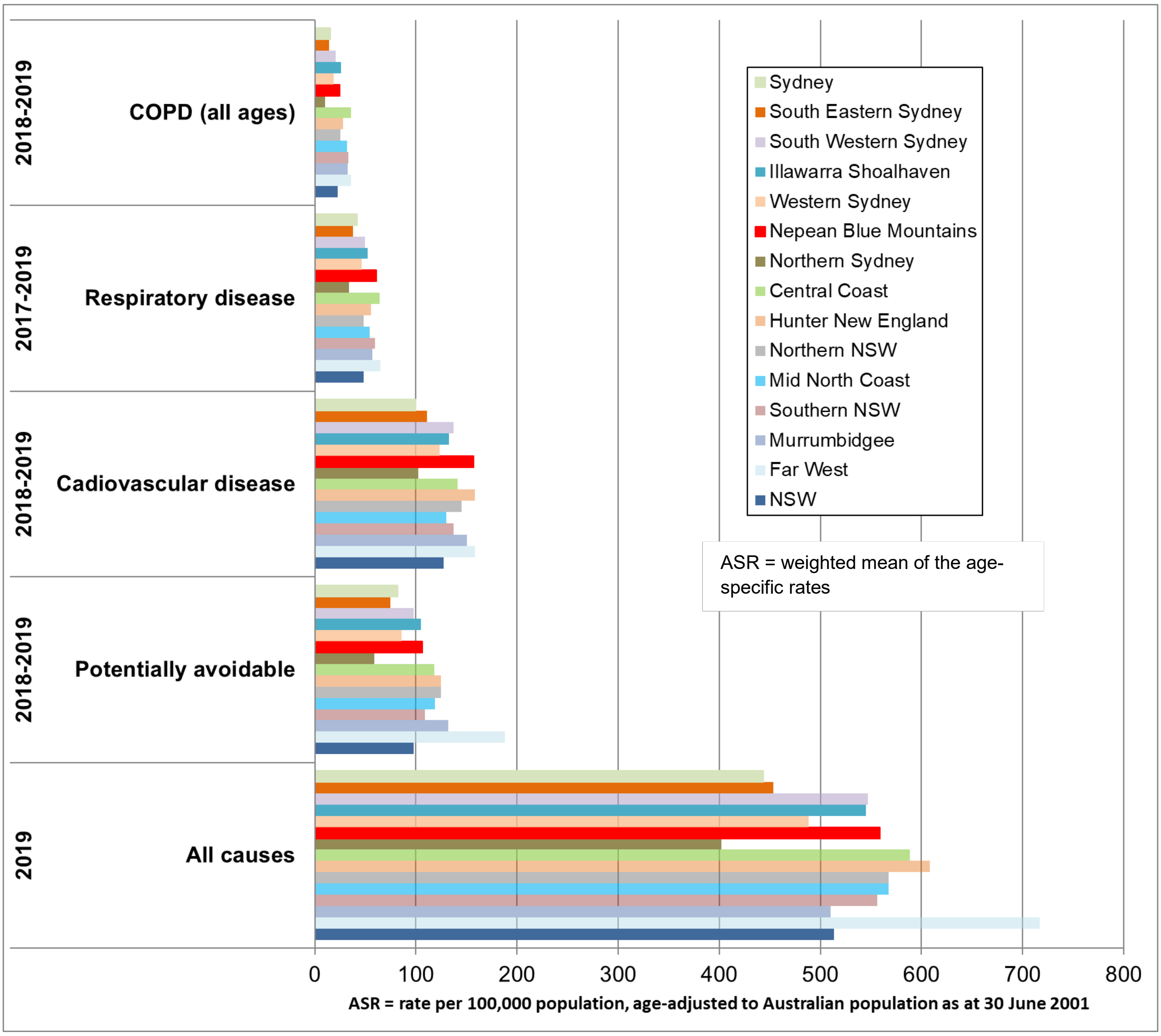


Figure 4-5: Summary of mortality data 2017-2019 (Source: HealthStats NSW 2022)

The study area is located in the Nepean Blue Mountains Local Health District (red bars).

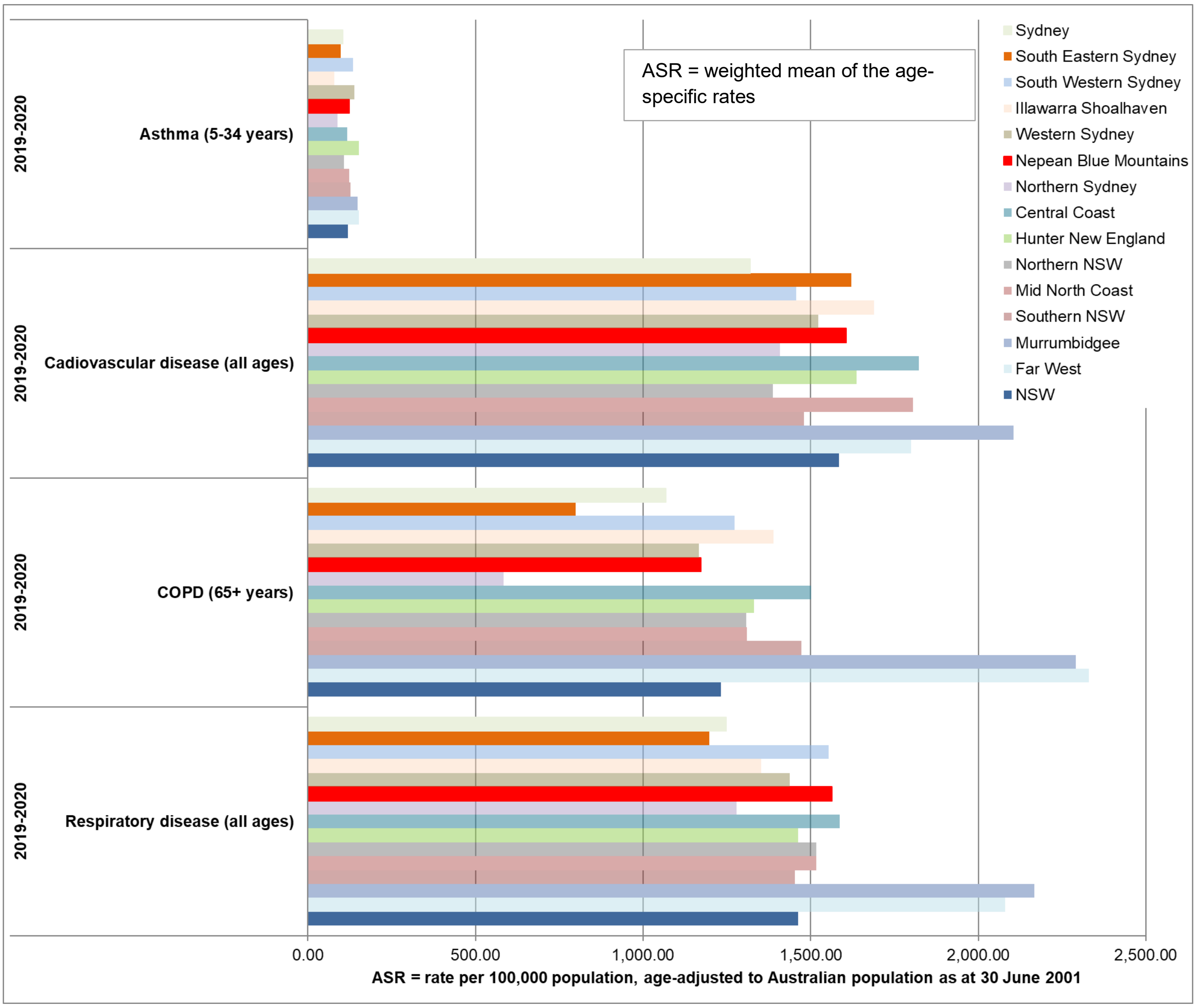


Figure 4-6: Summary of hospitalisation data 2019-2020 (Source: HealthStats NSW 2022)

The study area is located in the Nepean Blue Mountains Local Health District (red bars).

Review of the figures presented above indicate that the rate of mortality for the indicators presented in the Nepean Blue Mountains local health district are higher than that reported for NSW.

Review of the figures also show that the rate of hospitalisations for the indicators presented in the Nepean Blue Mountains local health district is significantly lower than that reported for NSW.

Table 4-4 presents specific health data relevant to mortality and hospitalisations, addressing all cases as well as respiratory and cardiovascular disease, as well as health indicators relevant to asthma and mental health. These are data that are specifically relevant to the quantification of exposure to nitrogen dioxide and particulate matter presented in **Section 5**.

Table 4-4: Summary of key health indicators

Health indicator	Rate per 100,000 population (unless otherwise indicated)			
	LGAs		Local health district	NSW
	Blue Mountains	Lithgow	Nepean Blue Mountains	
Mortality				
All causes – all ages (2019)			558.7	513.8
All causes (non-trauma) ≥30 years				
All causes ≥30 years				
Cardiovascular – all ages (2018-2019)	133.2	148.7	157.0	127.3
Respiratory – all ages (2017-2019)			60.9	48.7
Hospitalisations				
Coronary heart disease (2018-2020 for LGAs otherwise 2019-2020)	494.3	531.9	512.1	468.2
COPD All ages (2019-2020)	--	--	205.3	204.9
COPD >65 years (2018-2019 for LGAs** oherwise2019-2020)	880.3	2055.5	1172.5	1231.4
Cardiovascular disease				
All ages (2018-2019 for LGAs otherwise 2019-2020)	1503.3	1640.8	1605.0	1583.8
>65 years (2018-2019)**	6002.6	6448.5	--	6405.7
Respiratory disease				
All ages (2018-2020 for LGAs otherwise 2019-2020)	1503.3	1640.8	1563.2	1462.5
>65 years (2018-2019)**	3250.9	4978.4	--	4069.2
Asthma				
Asthma hospitalisations (ages 5–34 years) (2018- 2020 for LGAs, otherwise 2019-2020)	137.7	109.7	123.0	119.2
Asthma emergency department hospitalisations (all ages, unless specified) (2020-2021) (LGA data for 2018-2019*)	541.9 (0-14 years hospital admissions)	531.2 (0-14 years hospital admissions)	176.8	200.1 Children: 5-9: 602.6 10-14: 277.4
Asthma prescriptions (ages 3-19 years) 2013-2014**	30903	23180	--	31527
Asthma prevalence (current) for children aged 2–15 years	--	--	18.2%	13.1%
Current asthma for ages 16 and over	--	--	18.9%	11.5%
Mental health (rate per 1000 population)				
Number of prescriptions for antidepressants (2018-2019)*	1876.7	1853.0	1575.6	1408.6

Data from NSW Health Stats unless otherwise indicated

** Data from the Australian Institute of Health and Welfare on mental health prescriptions. Data provided for Blue Mountains and Lithgow-Mudgee areas.

*** Data from the Social Health Atlas of Australia, Child and Youth Social Health Atlas of Australia and the Social Health Atlas of Older People in Australia, https://phidu.torrens.edu.au/

Shaded cells are statistics directly used in the quantification of impacts from changes in air quality

The table presents data, where available, for the slightly smaller population areas in the LGAs in the study area with comparison against data for the Nepean Blue Mountains Local Health District and NSW.

In relation to mental health, data from NSW Health indicates the following for adults:

- the rate of high or very high psychological distress in adults reported in 2020 in the Nepean Blue Mountains Local Health District (17.5%) is a little higher than the state average (16.7%), however the difference is not considered to be statistically significant
- the rate of high or very high psychological distress for school students in 2017 in Western Sydney and Nepean Blue Mountains Local Health Districts (data is combined for these

areas) (13.5%) is slightly lower than the state average (14%), however the difference is not considered to be statistically significant.

Review of the data presented in **Table 4-4** and generally indicates the following:

- in relation to data available for the LGAs:
    - the population in the study area is expected to be more similar to the population in the Blue Mountains LGA due to the small size of the population located just outside of this LGA. The Lithgow LGA covers an area where the larger population areas are located well away from the study area
    - health data for the population in the Blue Mountains LGA is similar to NSW noting a slightly lower rate of cardiovascular disease and slightly higher ate of respiratory disease including a higher rate of asthma hospitalisations
    - health data for the population in the Lithgow LGA indicates higher rates of most health indicators when compared with NSW, with the exception of cardiovascular disease hospitalisations for people aged 75 years and older
    - in relation to mental health, data available for both Blue Mountains and Lithgow areas indicate a higher rate of prescriptions than NSW, suggesting a higher rate of pre-existing mental health issues in the population.
- in relation to the Nepean Blue Mountains Local Health District:
    - this covers a significantly larger population area than the study area, however the health data suggests higher rates of cardiovascular and respiratory hospitalisations and mortality than NSW
    - the area has a higher rate of asthma prevalence in adults and children, and a higher rate of asthma hospitalisations, however the rate of emergency department admissions for asthma are lower than NSW
    - in relation to mental health, the data indicates a higher rate of prescriptions than NSW, suggesting a higher rate of pre-existing mental health issues in the population.

4.6 Overview of existing community and health

The overall demography and health of the broader community is generally consistent with the NSW population. However, at a local level the population has some behaviours (smoking, alcohol consumption, lower intakes of fruit and higher rates of overweight and obese) that may be factors in the existing health of the community.

Health data is not available for the smaller population within the study area, however data for the broader community indicate that health conditions may not be as well managed as other areas of NSW, as there is a higher level of mortality but lower levels of hospitalisations for cardiovascular and respiratory disease.

Based on the available data the population may have some sensitivity to changes associated with the project. However, there may be health benefits from the long-term redistribution of traffic, and a reduction in transport related impacts related to the operation of the project. This is further evaluated in this report.

Section 5. Assessment of impact of changes in air quality on health

5.1 Approach

This section assesses the potential for changes in air quality due to the project and how these changes might impact health within the community. This assessment has drawn on information provided in Appendix E (Technical report - Air Quality) of the EIS and, in some areas, provides a summary of key (and relevant) aspects. All details relevant to the underlying assumptions, methodology and interpretation of impacts relevant to changes in air quality are provided within Appendix E (Technical report - Air Quality) of the EIS. Where more detail than provided in the health impact assessment is required, the reader is directed to Appendix E (Technical report - Air Quality) of the EIS.

The characterisation of health impacts from changes in air quality as a result of the project is complex.

This section presents an overview of the key aspects of the air quality impact assessment and an assessment of potential health impacts associated with the predicted changes in air quality in the local community. The assessment includes:

- Information on existing air quality (Appendix E (Technical report - Air Quality) of the EIS), presented in **Section 5.2**
- Summary of air quality impact assessment (Appendix E (Technical report - Air Quality) of the EIS), presented in **Section 5.3**
- Assessment of construction impacts on health, presented in **Section 5.4**
- Detailed assessment of the individual identified air quality parameters (exposure and potential impacts), presented in **Sections 5.5 to 5.8.**

The air quality impact assessment evaluated incremental changes in the relevant air quality parameters (i.e. changes in concentrations due to the project alone) and cumulative (i.e. background plus project) changes, which are those from the project added to the background air quality in the project area. Both the incremental and cumulative changes, relevant to the operational phase of the project, were used for the health impact assessment to assess potential impacts to health.

The assessment of health impacts associated with the operation of the project involves the quantification of health risks and impacts.

The quantification of health impacts from changes in air quality requires the use of a few different approaches to address the range of air pollutants relevant to this project:

- **Use of health based air guidelines**: For air pollutants where there is a threshold for acute and chronic effects (i.e. a level below which there are no health impacts), published health based guidelines have been identified and used in this assessment. The assessment of health impacts has focused on the maximum impacted locations and compared the predicted concentration of these air pollutants in air (from the project as well as other urban sources) with the air guideline. Where the exposure concentration is less than the air guideline there is no risk. This approach applies to a number of air toxics (discussed further in **Section 5.5**) as well as carbon monoxide (discussed further in **Section 5.6**).

- **Calculation of an incremental lifetime cancer risk:** For air pollutants that are considered to be genotoxic carcinogens, there is no threshold. Hence the approach adopted for the assessment of these chemicals is to calculate an incremental lifetime cancer risk, utilising published non-threshold inhalation toxicity reference values (or unit risk values), and an estimation of the maximum increase in air concentration (or exposure) within the community. This results in the calculation of an incremental carcinogenic risk and utilises commonly used risk assessment methods as outlined by enHealth (enHealth 2012a).

  As the methodology adopted for the assessment of an incremental carcinogenic risk is commonly used in risk assessments, there are a range of existing guidance where acceptable risk levels have been determined for population wide exposures (relevant to establishing drinking water guidelines (NHMRC 2011 updated 2022)).

  > **For this assessment, negligible risks are those where the incremental carcinogenic risk is ≤ 1 x 10^{-6}**

  For the assessment of individual risks, the level of acceptable risk is 10 times higher, consistent with the approach as detailed in the NEPM (NEPC 1999 amended 2013b) and enHealth (enHealth 2012a).

  > **For this assessment, acceptable maximum individual risks are those where the incremental carcinogenic risk is ≤ 1 x 10^{-5}**

  This approach applies to the assessment of community exposure to benzene, 1,3-butadiene, carcinogenic polycyclic aromatic hydrocarbons and diesel particulate matter (as discussed further in **Section 5.5**).

- **Calculation of impacts, risks and health burden, of changes in nitrogen dioxide and particulate matter:** The data available on health impacts from exposure to nitrogen dioxide and particulate matter, particularly within urban air environments, comes from large population or epidemiological studies. These studies enable relationships between exposure and various health effects (specifically mortality [i.e. a shortening of life-span] and morbidity effects). These concentration-response or exposure-response relationships are developed based on large population exposures and are utilised in the assessment of population health, and for establishing ambient (population wide) air guidelines. These relationships are not developed for the assessment of specific sources or localised impacts, as is the case for the assessment of impacts from the project.

  The project involves the construction of new roadway infrastructure that would result in the redistribution of traffic within the community, rather than constructing a new source. As a result, vehicle emissions within the broader community remain much the same which makes the conduct of community or larger population wide assessments of health impacts difficult as the overall health impact is expected reflect the small change in total vehicle movements. However, as traffic is more locally redistributed it is important to also evaluate the potential significance of this redistribution, particularly localised increases in exposure. While this may only affect a small number of households, increases in risk associated with these maximum changes also need to be considered. Hence this assessment has considered community health impacts, to inform the assessment of the overall health burden of the project, as well as localised health impacts, to inform management decisions in relation to the magnitude of localised impacts.

Community/population health impacts have been assessed on the basis of the overall change in population risk (within the relevant LGAs) and health incidence (change in the number of cases). There is very limited guidance available in relation to acceptability of community risks associated with changes in airshed concentrations of nitrogen dioxide and particulate matter (refer to **Annexure C** for further discussion). However for the purpose of this assessment guidance available from the NEPC, relevant to the assessment of population exposures to air pollutants (including nitrogen dioxide and particulate matter) indicates that the estimated risk from population exposures should not exceed one additional case per 100,000 of the population per year (NEPC 2011). Hence the following has been adopted:

For this assessment, acceptable population risk for nitrogen dioxide or particulate matter is ≤ 1 x 10^{-5}

Localised health impacts have also been calculated to assess the potential significance of maximum increases in nitrogen dioxide and particulate matter as a result of the localised redistribution of traffic. As this is a localised impact it is not possible to calculate an increased population incidence and the calculation of risk relates to a maximum localised risk, not a population risk. Due to the limitations of applying the exposure-response functions to localised impacts, these localised risks are considered to only be semi-quantitative. There is no guidance available for the assessment of localised risks for changes in nitrogen dioxide or particulate matter. **Annexure C** provides additional discussion in relation to determining various risk levels. Based on the discussion provided in **Annexure C**, and consideration of the need to determine an action level for the management of localised impacts, a risk management level that is equal to the level at which risks are considered unacceptable has been adopted in this assessment has follows:

For this assessment, the risk management level for localised risk ≥ 1 x 10^{-4}

Calculated population risks and localised risks for changes in nitrogen dioxide and particulate matter are presented in **Sections 5.7 and 5.8**.

The assessment of health impacts from changes in air quality has utilised outputs from the air quality modelling that are presented within Appendix E (Technical report - Air Quality) of the EIS. In addition, the health impact assessment has also utilised predicted annual average data for all receptors considered in the air quality modelling. These additional data have been provided, from the air quality modelling, for use in the health impact assessment.

It is noted that the assessment of air quality impacts has adopted incremental assessment criteria for $PM_{2.5}$ and NO_2. This established incremental criteria for these pollutants using a modified version of the UK approach provided by IAQM (IAQM 2017). The incremental criteria have been developed on the basis of the incremental change in air concentrations (as an annual average) for individual receptors as a proportion of the ambient air quality criteria with qualitative descriptors used to determine impacts that include negligible, slight, moderate and substantial. The criteria adopted are detailed further in **Table 5-1** and **Table 5-2**.

Table 5-1: Project impact criteria for annual average $PM_{2.5}$ individual receptors

Total concentration at receptor for a given averaging period	Absolute change in concentration relative to air quality criterion				
	<0.5% (<0.04 µg/m³)	≥0.5% to <1.5% (≥0.04 to <0.12 µg/m³)	≥1.5% to <5.5% (≥0.12 to <0.44 µg/m³)	≥5.5% to <10.5% (≥0.44 to <0.84 µg/m³)	≥10.5% (≥0.84 µg/m³)
≤75% of AQC (≤6.0 µg/m³)	Negligible	Negligible	Negligible	Slight	Moderate
>75% to ≤95% of AQC (>6 to ≤7.6 µg/m³)	Negligible	Negligible	Slight	Moderate	Moderate
>95% to ≤103% of AQC (<7.6 to ≤8.2 µg/m³)	Negligible	Slight	Moderate	Moderate	Substantial
>103% to ≤110% of AQC (>8.2 to ≤8.8 µg/m³)	Negligible	Moderate	Moderate	Substantial	Substantial
≥110% of AQC (≥8.8 µg/m³)	Negligible	Moderate	Substantial	Substantial	Substantial

Table 5-2: Project impact criteria for annual average NO_2 individual receptors

Total concentration at receptor for a given averaging period	Absolute change in concentration relative to air quality criterion				
	<0.5% (<0.16 µg/m³)	≥0.5% to <1.5% (≥0.16 to <0.47 µg/m³)	≥1.5% to <5.5% (≥0.47 to <1.71 µg/m³)	≥5.5% to <10.5% (≥1.71 to <3.26 µg/m³)	≥10.5% (≥3.26 µg/m³)
≤75% of AQC (≤23.3 µg/m³)	Negligible	Negligible	Negligible	Slight	Moderate
>75% to ≤95% of AQC (>23.3 to ≤29.5 µg/m³)	Negligible	Negligible	Slight	Moderate	Moderate
>95% to ≤103% of AQC (<29.5 to ≤31.9 µg/m³)	Negligible	Slight	Moderate	Moderate	Substantial
>103% to ≤110% of AQC (>31.9 to ≤34.1 µg/m³)	Negligible	Moderate	Moderate	Substantial	Substantial
≥110% of AQC (≥34.1 µg/m³)	Negligible	Moderate	Substantial	Substantial	Substantial

5.2 Existing air quality

The existing environment for the project has been evaluated in detail in Appendix E (Technical report - Air Quality) of the EIS.

Meteorological analysis focused on the Mt Boyce Bureau of Meteorology station given the lack of suitable alternative data for the region. The Mt Boyce data set presented a good long term data set that is considered representative of the condition at the top of the Blue Mountains. Meteorology showed a predominance of westerly and east north-easterly winds with minor lower proportion of winds from the west-southwest and east. Calm conditions were low with average calms of about two per cent observed between 2010 and 2020 with an average wind speed of 1.9 metres per second. Differences were expected between Mt Boyce and Little Hartley, and these have been addressed in the air quality modelling that predicted higher calm conditions at Little Hartley, which is consistent with expectations for that area.

Topography along the project corridor is dominated by the western escarpment of the Blue Mountains Plateau and lower elevations in the Little Hartley Valley. Substantial topographical changes occur close to the western portal location which have the potential to affect the dispersion pattern of the westbound ventilation outlet.

Existing pollutant levels showed that, when compared with existing NSW EPA standards, all monitored pollutant (NO_2, CO and particulate) concentrations fall well below their respective standards at all project monitoring stations. A full year of monitoring data was not available for the project, so a unified monitoring data set was generated based on project concentrations and expected meteorological conditions. Cumulative modelling concentrations were calculated based on this data.

5.3 Overview of air quality impact assessment

5.3.1 General

The assessment of air quality impacts associated with the project is presented in Appendix E (Technical report - Air Quality) of the EIS. The assessment evaluated changes in air quality in the local community as a result of emissions to air from two different ventilation options (the tunnel portals and ventilation structures) (refer to **Section 5.3.3.1**), and changes in emissions from traffic on major roadways in the project area.

5.3.2 Construction

Appendix E (Technical report - Air Quality) of the EIS evaluated impacts on air quality that may occur during construction. The assessment considered impacts that may occur during tunnelling activities and surface works and involved a qualitative assessment approach.

The location of human (and ecological) receptors in the vicinity of the project's three construction sites were identified (relevant to the assessment of both tunnel ventilation options). The receptors evaluated surrounding the construction sites were:

- Blackheath (construction footprint of around 26 hectares) (refer to **Figure 1-5**) - Human receptors within 350m of the site. Land use is primarily relatively undisturbed vegetation, with some residential, accommodation and recreational properties.
- Soldiers Pinch (construction footprint of around 67 hectares) (refer to **Figure 1-6**) - Human receptors within 350m of the site. Land use is primarily relatively undisturbed vegetation, there is a public recreational area to the northwest of the boundary. The nearest residential receptor is located outside the 350m boundary.
- Little Hartley (construction footprint of around 103 hectares) (refer to **Figure 1-7**)- Human receptors within 350m of the site. Land use is primarily relatively undisturbed vegetation, and rural residential and agricultural land.

The qualitative assessment considered potential impacts at 50 m and 350 m screening distances from these zones as well as within additional buffer zones of 20 m, 100m and 200m.

All construction activities proposed to be undertaken relating to demolition, earthworks, construction and trackout were identified with the magnitude of these works categorised as small, medium or large.

The sensitivity of the surrounding community to unmitigated dust impacts was evaluated within the various distances from the works where there following was determined:

- at Blackheath the risk of dust is high due to the proximity (within around 20 metres) of highly sensitive residential receptors on the border of the construction footprint, with a medium risk identified within around 50 metres
- at Soldiers Pinch the risk of dust due to the presence of a single low sensitivity recreational receptor (Browntown Oval) and no residential receptors within the screening distances
- at Little Hartley the risk of dust is low due to limited proximity (within around 100 metres) of highly sensitive rural receptors.

The sensitivity of the surrounding community to exposure from unmitigated dust generated from the proposed works was then determined. This part of the qualitative assessment relates to the potential for impacts on health.

The qualitative assessment concluded that the health risk from PM_{10} emissions is low at all construction sites due to the low PM_{10} background concentrations and to the limited number of sensitive receptors at Little Hartley and Soldiers Pinch.

Regardless of the outcome indicated above in relation to health, the potential for unmitigated dust impacts to be in the range negligible to high triggers the need for the implementation of dust mitigation measures. The implementation of these measures as detailed in Appendix E (Technical report - Air Quality) of the EIS would further reduce any impacts on health as a result of the proposed construction works.

Exposure to combustion emissions (i.e., from the use of petrol and diesel fuel by light and heavy vehicles and construction equipment, including generators) was also assessed in Appendix E (Technical report - Air Quality) of the EIS. The assessment concluded that these emissions are unlikely to make any significant impact or change in local air quality. Hence these emissions are not considered to be of concern in relation to community health. These conclusions apply to the assessment of construction impacts for both tunnel ventilation options.

5.3.3 Operations

5.3.3.1 Assessment scenarios

Vehicle emissions from the operational project would include both exhaust and non-exhaust emissions. Exhaust pollutant emissions are due to fuel combustion and include the gaseous pollutants NO_2, CO, PAHs and VOCs as well as particulates (PM_{10} and $PM_{2.5}$). Vehicle emission rates are affected by a wide range of factors including vehicle numbers, vehicle speeds, road grades, vehicle fleet mix over time and the resulting changes to emission factors (over time the car fleet changes with older cars being replaced with newer cars which emit lower amounts of pollution resulting in lower overall fleet emissions).

Dispersal of vehicle emissions can also be influenced by road design features. Surface roads allow open air dispersal of air pollutants at ground level; with ground level pollutant concentrations generally falling to background concentrations within 50 to 100 metres of the kerb. Within road tunnels emitted pollutant concentrations accumulate within the tunnel and tunnel air concentration is generally higher at the outlet location, which then relies on more enhanced dispersal through portals and/or through mechanical ventilation.

Appendix E (Technical report - Air Quality) of the EIS has considered two ventilation options, which are also considered in this assessment (as illustrated in **Figure 5-1**):

1. Ventilation via ventilation outlets. A ventilation outlet would be placed at both the eastern and western ends of the tunnel. Air is extracted from the tunnel via mechanical ventilation and is dispersed at height via the ventilation outlet. This method results in a wider plume dispersion pattern, or footprint, for air pollutants resulting in a different concentration dispersion profile around the outlet as compared with portal emissions. Portal emissions under this configuration are considered negligible.
2. Ventilation via the exit portal. Air from within the tunnel is drawn through the tunnel via both the piston affect from moving vehicles and via mechanical ventilation (jet fans) when needed. This option results in higher concentrations of vehicle emissions occurring close to the exit portals.

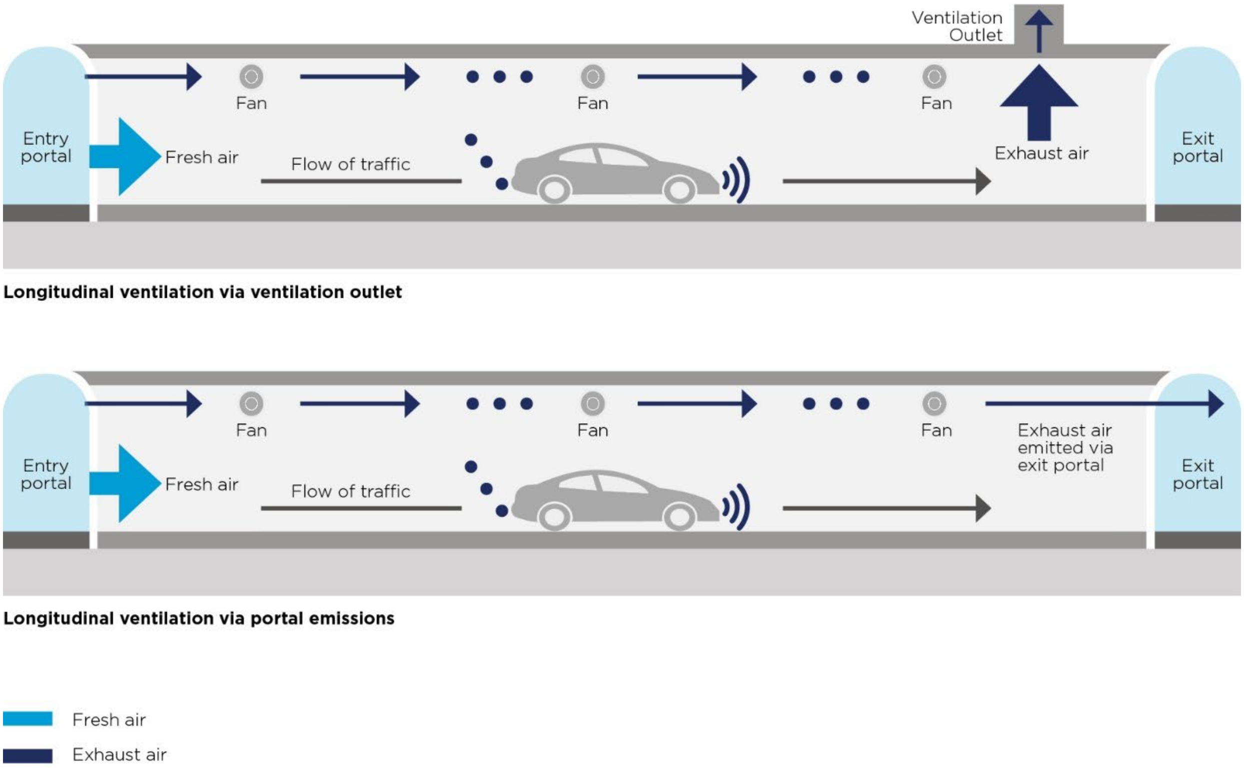


Figure 5-1: Ventilation system options for the project (from Appendix E (Technical report - Air quality) of the EIS)

For each of these ventilation options the assessment has considered three different scenarios for daily traffic movements:

- ***Typical daily traffic profile*** – the typical daily traffic profile reflects the expected hourly traffic numbers using the tunnel on a normal day (excluding peak traffic days such as Christmas and Easter and long weekend holidays and during special events such the Bathurst Super Car event). This profile is considered to provide the best indication of long-term impacts from the tunnel operations.

  This data has been used in this assessment as representative of potential chronic exposures (i.e. where an annual average air concentration is evaluated).

- ***Maximum daily traffic profile*** – the maximum daily traffic profile reflects traffic conditions that are only expected to occur for a small number of days per year e.g., during the Bathurst race weekend or at Christmas with high tourist numbers. As this is not expected to occur across many days per year, only short-term pollutant averaging periods have been considered for the assessment. This is considered to best represent the tunnels worst-case short-term traffic conditions.

  This data has been used in this assessment as representative of maximum short-term or acute exposures (i.e. where short-term average air concentrations are evaluated including 1-hour, 8-hour and 24-hour averages as relevant to the pollutant being evaluated).

- ***Regulatory worst-case emissions traffic profile*** – this reflects emissions that could theoretically occur when tunnel emissions are equal to the emission concentrations included in the tunnel environment protection licence (EPL). Although licence conditions are not currently applicable to portal emissions, both ventilation outlet and portal emission configurations have been considered for the regulatory worst-case scenario.

  This scenario is considered to be hypothetical for the purpose of establishing an appropriate EPL for the project. This is based on the situation where emissions to air from the tunnel ventilation outlets occur at the maximum discharge limits at all hours of the day. This may occur in the event of a breakdown or accident and may result in a short period of time where emissions from the tunnel ventilation facility are higher than during normal operations. Such situations are not planned and where they occur the duration of the event is not expected to last for longer than a few hours. Hence this data has been used in this assessment as representative of maximum short-term or acute exposures (i.e., where short-term average air concentrations are evaluated including 1-hour, 8-hour and 24-hour averages as relevant to the pollutant being evaluated)

The modelling of air emissions evaluated the following:

- three baseline operational scenarios were modelled that reflect emissions from surface roads only i.e., without the project. Emissions were calculated based on surface road traffic data for 2018 (baseline scenario), 2030 and 2040 time periods (future baseline scenarios) assuming the project has not been constructed
- two future operational scenarios were modelled that reflect emissions from the tunnel and surface roads for the typical daily traffic emission profiles during 2030 (at project opening) and 2040 (10 years after project opening). Both future scenarios were modelled for both ventilation options (i.e., ventilation outlet and portal emissions).

For the assessment of impacts on health, the following has been utilised from the air modelling:

- total concentrations in air (background plus project) in 2030 and 2040 for the three traffic scenarios (typical daily traffic, maximum daily traffic and regulatory worst-case) and the two different ventilation scenarios
- incremental concentrations (change in concentrations with project compared with without project (or baseline)) in 2030 and 2040 for the three traffic scenarios (typical daily traffic, maximum daily traffic and regulatory worst-case) and the two different ventilation scenarios.

5.3.3.2 Outcome of air quality impact assessment

Appendix E (Technical report - Air Quality) of the EIS provides detail on the approach used to model and assess air quality impacts associated with the project. In relation to the assessment of operational impacts, a quantitative approach was used, with ambient air concentration in the surrounding community modelled on the basis of an air dispersion model, GRAL. The model incorporates project specific meteorological data, terrain data, land use data, building data, receptor locations and source emissions data.

The modelling was used to calculate concentrations of a range of key pollutants associated with emissions from vehicles at each of the receptor locations evaluated in the study area. The pollutants evaluated included:

- particulates as PM_{10} and $PM_{2.5}$
- oxides of nitrogen (NOx), and NO_2 (which is part of NOx)
- carbon monoxide (CO)
- benzene
- toluene
- xylenes
- 1,3-butadiene
- formaldehyde
- acetaldehyde
- polycyclic aromatic hydrocarbons (PAHs) assessed on the basis of a benzo(a)pyrene (BaP) toxicity equivalent concentration.

The air quality assessment considered air criteria for the above pollutants from NSW EPA (2017). The assessment presented in Appendix E (Technical report - Air Quality) of the EIS concluded that impacts on air quality from the project are considered to be low, with all predicted concentrations below the adopted air criteria.

In relation to the assessment of impacts on individual receptors, based on the impact assessment criteria as detailed in **Section 5.3**, the assessment considered background concentrations for NO_2 and $PM_{2.5}$ and the change in concentration relative to the air quality criteria as a result of the project.

The background concentration adopted for the project are:

- nitrogen dioxide annual average concentration of $6.3\mu g/m^3$
- $PM_{2.5}$ annual average concentration of $5.2\mu g/m^3$

Table 5-3 presents a summary of the impact assessment completed using this methodology.

Table 5-3: Project impact assessment outcomes (summarised from Appendix E (Technical report - Air Quality) of the EIS)

Scenario	Nitrogen dioxide		$PM_{2.5}$	
	Maximum increase in annual average concentration (mg/m^3)	Impact assessment	Maximum increase in annual average concentration (mg/m^3)	Impact assessment
Typical traffic scenario				
Portal emissions				
2030	16.3	Negligible to slight	0.52	Negligible
2040	9.4	Negligible	0.57	Negligible
Ventilation outlet emissions				
2030	11.3	Negligible	0.23	Negligible
2040	8.5	Negligible	0.23	Negligible

Impacts related to increases in $PM_{2.5}$ are considered to be negligible for both portal emissions and ventilation outlet emissions. For increases in NO_2, in 2030 for portal emissions the impacts are ranked negligible to slight, with the slight descriptor applying to two receptors. These impacts do not remain in 2040.

Further to the impacts summarised above in relation to increases in annual average concentrations, for all scenarios evaluated there are a significant number of receptors where there is a decrease in NO_2 or $PM_{2.5}$ concentrations with the project, as follows:

- for portal emissions there would be a decrease in pollutant concentrations at 81 percent (for $PM_{2.5}$) to 90 percent (for NO_2) of receptors in 2030 and 77 percent (for $PM_{2.5}$) to 82 percent (for NO_2) of receptors in 2040.
- for ventilation outlet emissions there would be a decrease in pollutant concentrations at 76 percent (for $PM_{2.5}$) to 79 percent (for NO_2) of receptors in 2030 and 73 percent (for $PM_{2.5}$) to 95 (for NO_2) percent of receptors in 2040.
- The impact of the above decreases range from negligible to substantial.

Overall, the assessment of potential impacts of the project on air quality were considered low. More specifically, in relation to NO_2 and $PM_{2.5}$ the assessment concluded negligible risks to individual receptors in the surrounding community.

5.4 Assessment of construction health impacts

If construction impacts are not mitigated or managed, there are a range of potential impacts on the health of the community. Certain air emissions, such as fine particulate matter, can affect the health of residents. While nuisance issues such as the deposition of larger dust (i.e. greater than PM_{10}) do not directly impact on health, the deposition of enough dust can pose a nuisance. Such nuisance impacts can increase levels of stress and anxiety, with the community perceiving the presence of significant and visible amounts of dust as potentially affecting their health. Odours can also pose a nuisance, with some also considered to be noxious which can make the community feel unwell.

The assessment of impacts during construction presented in Appendix E (Technical report - Air Quality) of the EIS determined that unmitigated dust impacts pose a low risk to community health. Odours are not expected to be of significance in the project works. Dust and odour mitigation, however, is proposed during construction and include measures AQ1 to AQ13 (refer to Appendix E (Technical report - Air Quality) of the EIS). Implementation of these measures would result in further reductions in impacts and the potential for health impacts. No further detailed assessment of air quality impacts on health during construction has been undertaken.

5.5 Assessment of operational health impacts – air toxics

The operational air quality impact assessment for the project (Appendix E (Technical report - Air Quality) of the EIS) considered emissions of air toxics, specifically benzene, toluene, xylenes, 1,3-butadiene, formaldehyde and polycyclic aromatic hydrocarbons (PAHs) (as benzo(a)pyrene equivalents) to air from the project.

Most of the volatile organic compounds (VOCs) emitted from vehicles comprise a range of hydrocarbons of low toxicity (such as methane, ethylene, ethane, butenes, butanes, pentenes, pentanes and heptanes) (NSW EPA 2012). From a toxicity perspective, the key VOCs considered for the vehicle emissions are benzene, toluene, xylenes, 1,3-butadiene and formaldehyde (consistent with those identified and targeted in studies conducted in Australia on vehicle emissions (DEH 2003; NSW EPA 2012)). The emission rate of these VOCs is based on the traffic mix assumed for the project and emission rates relevant to the Australian vehicle fleet.

PAHs are predominantly derived from diesel exhausts, with the composition and concentrations dependant on the fuel and type of vehicle. The emission rate of PAHs from vehicles related to the project is based on the traffic mix relevant to the project, and the Australian vehicle fleet using Australian fuel. For this assessment only the conservative emissions estimates for the years 2026 and 2036 have been considered.

In relation to the toxicity of PAHs, this differs significantly for the different individual PAHs that may be present. However, it is common to evaluate PAHs as a group where the PAHs are summed together using toxicity equivalents. Toxicity equivalents are factors that relate the toxicity of an individual PAH to the most well understood and studied PAH, benzo(a)pyrene (BaP). This enables PAHs to then be assessed as a BaP toxicity equivalent concentration using the toxicity and health guidelines relevant to BaP. The assessment of PAHs was thus undertaken on the basis of a BaP toxicity equivalent concentration and using health guidelines for BaP.

In addition to the assessment of potential exposures to PAHs, this assessment has also considered exposure to diesel particulate matter (DPM). DPM includes PAHs, however DPM has been classified as a carcinogen by the International Agency for Research on Cancer (IARC) and it is relevant to also assess exposures to total DPM as well as the sub-set of PAHs.

The assessment of inhalation exposures associated with VOCs, PAHs and DPM has considered the following:

- health based air guidelines and inhalation toxicity reference values (TRVs) for carcinogenic compounds have been selected on the basis of guidance provided by enHealth (enHealth 2012a). It is noted that there is no one individual agency/organisation that provides the most robust and current guidelines and TRVs for the compounds considered in this assessment, as the relevant agencies/organisations do not necessarily review all the chemicals and do not update assessments on a regular basis. As a result, the guidelines and TRVs adopted in this assessment come from a number of different sources. The guidelines and TRVs adopted are based on consideration of the available information and reviews provided by relevant key organisations that undertake detailed evaluations of toxicity and determine quantitative values for the assessment of inhalation exposures. This information has been evaluated to determine the most appropriate value that can be used to quantify acute and chronic inhalation exposures. This requires consideration of the hazards identified and the mechanisms for action particularly in relation to the assessment of carcinogenic effects, transparency of the review (i.e. is all the information presented and the derivation of the guideline transparent), robustness of the evaluation (i.e. critical review and evaluation of all available and relevant studies), currency of the evaluation (including whether more recent key studies were considered) and the application of uncertainty factors

- for VOCs, PAHs and DPM which are considered genotoxic carcinogens (consistent with guidance provided by enHealth (enHealth 2012a)) an incremental lifetime carcinogenic risk has been calculated. For the VOCs and PAHs evaluated in this assessment a carcinogenic risk calculation has been adopted for the assessment of maximum potential (incremental) increase in benzene, 1,3-butadiene and PAHs assessed as a benzo(a)pyrene toxicity equivalent (TEQ). In addition, carcinogenic risks associated with exposure to DPM has been assessed. DPM has not been specifically modelled or assessed in the air modelling of vehicle emissions. For the purpose of this assessment, it has been assumed that 100% of $PM_{2.5}$ is DPM. The assessment undertaken has adopted the calculation methodology outlined in **Annexure B**, adopting the inhalation unit risk values presented in Table 5-5, and assuming the maximum impacts occur at a residential home where individuals are at home 24 hours per day, 365 days of the year and they live at the same house for 35 years (enHealth 2012b)
- for other VOCs, where the health effects are associated with a threshold (i.e., a level below which there are no effects), the maximum predicted concentration of individual VOCs (background plus the change due to the project) associated with the project have been compared against published peer-reviewed health-based guidelines relevant to acute and chronic exposures (where relevant). The health-based guidelines adopted (identified on the basis of guidance from enHealth 2012) are relevant to exposures that may occur to all members of the general public (including sensitive individuals) with no adverse health effects. The guidelines available relate to inhalation exposures from all sources and reflect duration of exposure where:
  1. acute guidelines are based on exposures that may occur for a short period of time (typically between 1 hour or up to 14 days). These guidelines are available to assess peak exposures (based on the modelled one-hour maximum concentration) that may be associated with VOCs in the air and are presented in **Table 5-4**.
  2. chronic guidelines are based on exposures that may occur all day, every day for a lifetime. These guidelines are available to assess long-term exposures (based on the modelled annual average concentration) that may be associated with VOCs in the air and are presented in
  3. **Table 5-5**. Use of these values assumes the maximum impact occurs at a residential home where individuals are at home 24 hours per day for 365 days of the year.

Table 5-4: Adopted acute inhalation guidelines based on protection of public health

Compound assessed	Acute health based guideline (µg/m³)	Basis
Benzene	580	Acute 1-hour health-based guideline, based on depressed peripheral lymphocytes from the Texas Commission on Environmental Quality (TCEQ) evaluation (TCEQ 2015).
Toluene	15,000	Acute 1-hour health-based guideline, based on eye and nose irritation, increased occurrence of headache and intoxication in human male volunteers from TCEQ evaluation (TCEQ 2013b).
Xylenes	7,400	Acute 1-hour health-based guideline, based on mild respiratory effects and subjective symptoms of neurotoxicity in human volunteers from TCEQ evaluation (TCEQ 2013a).
1,3-Butadiene	660	Acute 1-hour health-based guideline, based on developmental effects derived by the California Office of Environmental Health Hazard Assessment (OEHHA 2013). The guideline developed is lower than developed by TCEQ (TCEQ 2007) based on the same critical study.
Formaldehyde	100	Acute health-based guideline, based on changes in blink eye response in human volunteers (WHO 2000c, 2010).
Acetaldehyde	470	Acute 1 hour health based guideline, based on effects on sensory irritation, bronchoconstriction, eye redness and swelling derived by the California OEHHA (OEHHA 2013).

Table 5-5: Adopted chronic guidelines and carcinogenic unit risk values based on protection of public health

Compound assessed	Chronic health based guideline	Basis
Threshold guidelines		
Benzene	30 µg/m^3	The most significant chronic health effect associated with exposure to benzene is the increased risk of cancer, specifically leukaemia, which is assessed separately (below). The assessment of other health effects (other than cancer) has been undertaken using a chronic guideline derived by the USEPA (USEPA 2002a) based on haematological effects in an occupational inhalation study (converted to public health value using safety factors). This is the most current evaluation of effects associated with chronic inhalation exposure to benzene and is consistent with the value used to derive the NEPM (NEPC 1999 amended 2013c) health based guidelines.
Toluene	5,000 µg/m^3	Chronic guideline derived by the USEPA (USEPA 2005a) based on neurological effects in an occupational study (converted to public health value using safety factors). This is the most current evaluation of effects associated with chronic inhalation exposure to toluene and is consistent with the value used to derive the NEPM (NEPC 1999 amended 2013c) health based guidelines.
Xylenes	220 µg/m^3	Chronic guideline derived by ATSDR (ATSDR 2007) based on mild subjective respiratory and neurological symptoms in an occupational study (converted to public health value using safety factors).
Formaldehyde	100 µg/m^3	Formaldehyde is classified by IARC as carcinogenic to humans. The guideline developed by the WHO (WHO 2000c, 2010) is considered to be protective of both short and long-term exposures, for non-carcinogenic and carcinogenic health effects. Some lower guidelines are available from the US, however these are based on approaches to the assessment of carcinogenic effects inconsistent with that adopted by enHealth (enHealth 2012a) and the WHO (WHO 2010).
Acetaldehyde	9 µg/m^3	Chronic guideline derived by the USEPA (USEPA IRIS) based on nasal effects (in a rat study) (converted to a public health value using safety factors). Value is more conservative that more recent evaluations from WHO and Californian OEHHA.
Carcinogenic inhalation unit risk values adopted for carcinogenic risk calculation		
Benzene	6×10^{-6} (µg/m^3)$^{-1}$	Benzene is classified as a known human carcinogen by the International Agency for Research on Cancer (IARC). Inhalation unit risk value is from the WHO (WHO 2000c, 2010) and is based on excess risk of leukaemia from epidemiological studies.
1,3-Butadiene	5×10^{-7} (µg/m^3)$^{-1}$	1,3-Butadiene is classified as a known human carcinogen by the International Agency for Research on Cancer (IARC). Inhalation unit risk values are available from a number of agencies, including the WHO, USEPA and TCEQ. The most current evaluation has been undertaken by TCEQ (TCEQ 2013c). This has considered the same studies as WHO and USEPA but included more recent studies and more relevant dose-response modelling.
Benzo(a)pyrene TEQ	0.087 (µg/m^3)$^{-1}$	BaP is classified by IARC as a known human carcinogen, which relates to BaP as well as all the other carcinogenic PAHs assessed as a BaP toxicity equivalent (TEQ) value. Inhalation unit risk value is from the WHO (WHO 2010) and is based on protection from lung cancer for an occupational study associated with coke oven emissions. It is noted that carcinogenic risks associated with lung cancer from diesel particulate matter (which is dominated by the presence of carcinogenic PAHs) is also assessed separately.
Diesel particulate matter	3.4×10^{-5} (µg/m^3)$^{-1}$	DPM is classified by IARC as a known human carcinogen. Inhalation unit risk values are available from California (OEHHA 1998) as well as the WHO (WHO 1996), with the assessment provided by the WHO considered the more robust. The WHO value, adopted in this assessment is based on data from four different studies where lung cancer was the endpoint.

Table 5-6, Table 5-7 and Table 5-9 present a summary of the maximum predicted 1-hour or annual average concentrations of VOCs assessed by comparison against acute and chronic health based guidelines (developed using a threshold approach). Calculations associated with the analysis of the situation where the tunnel is operated at maximum capacity (i.e., maximum traffic and regulatory worst-case scenarios) are only relevant to the assessment of short-term acute exposures and are therefore not presented for chronic exposures. The tables also present a Hazard Index (HI) which is the ratio of the maximum predicted concentration to the guideline (i.e., maximum concentration/guideline). Each individual HI is added up to obtain a total HI for all the threshold VOCs considered. The total HI is a sum of the potential hazards associated with all the threshold VOCs together assuming the health effects are additive, and is evaluated as follows (enHealth 2012a):

- a total HI less than or equal to one means that all the maximum predicted concentrations are below the health based guidelines and there are no additive health impacts of concern
- a total HI greater than one means that the predicted concentrations (for at least one individual compound) are above the health based guidelines, or that there are at least a few individual VOCs where the maximum predicted concentrations are close to the health based guidelines such that there is the potential for the presence of all these together (as a sum) to result in adverse health effects.

Table 5-9 summarises calculated incremental lifetime carcinogenic risk associated with chronic exposure to the maximum predicted annual average concentrations of benzene, 1,3-butadiene and carcinogenic PAHs as benzo(a)pyrene TEQ. The calculated carcinogenic risk for these compounds has been summed for benzene, 1,3-butadiene and carcinogenic PAHs, in accordance with enHealth guidance (enHealth 2012a). The calculated carcinogenic risk for DPM has not been summed as this assessment includes particulate bound chemicals. Summing DPM with the other carcinogenic compounds would result in significant double counting of risks. Incremental carcinogenic risks have been assessed against the criteria discussed in **Section 5.1**.

The values presented in the tables have been rounded to two significant figures for individual calculations and one significant figure for the total HI and total carcinogenic risk, reflecting the level of uncertainty in the calculations presented.

Table 5-6: Assessment of acute exposures – Typical traffic scenario

VOC assessed	Acute air guideline (µg/m³)	Modelled maximum 1-hour average air concentrations* (µg/m³)				Calculated HI			
		2030		2040		2030		2040	
		Without project	With project	Without project	With project	Without project	With project	Without project	With project
Portal emissions									
Benzene	580	0.15	0.044	0.081	0.10	0.00026	0.000076	0.00014	0.00017
Toluene	15000	0.32	0.093	0.17	0.21	0.000021	0.0000062	0.000011	0.000014
Xylenes	7400	0.24	0.069	0.13	0.16	0.000032	0.0000094	0.000017	0.000021
1,3-Butadiene	660	0.035	0.010	0.019	0.023	0.000053	0.000015	0.000028	0.000035
Formaldehyde	100	0.066	0.019	0.041	0.052	0.0007	0.00019	0.00041	0.00052
Acetaldehyde	470	0.036	0.010	0.019	0.024	0.000076	0.000022	0.000041	0.000051
					Total HI	**0.0011**	**0.00032**	**0.00065**	**0.00081**
					% change in HI with project		-71%		25%
Ventilation outlet emissions									
Benzene	580	0.15	0.036	0.081	0.035	0.00026	0.000061	0.00014	0.000061
Toluene	15000	0.32	0.076	0.17	0.074	0.000021	0.0000050	0.000011	0.0000050
Xylenes	7400	0.24	0.056	0.13	0.055	0.000032	0.0000076	0.000017	0.0000075
1,3-Butadiene	660	0.035	0.0083	0.019	0.0081	0.000053	0.000013	0.000028	0.000012
Formaldehyde	100	0.066	0.016	0.041	0.018	0.0007	0.00016	0.00041	0.00018
Acetaldehyde	470	0.036	0.0083	0.019	0.0084	0.000076	0.000018	0.000041	0.000018
					Total HI	**0.0011**	**0.00026**	**0.00065**	**0.00028**
					% change in HI with project		-76%		-56%
					Acceptable HI	**≤1**	**≤1**	**≤1**	**≤1**

* Maximum 1-hour average air concentrations based on the modelled 99.9th percentile concentration which is considered representative of the maximum plausible air concentration that may be present.

Table 5-7: Assessment of acute exposures – Maximum daily and Regulatory worst-case traffic scenarios

VOC assessed	Acute air guideline (µg/m³)	Modelled maximum 1-hour average air concentrations* (µg/m³)				Calculated HI			
		2030		2040		2030		2040	
		Max traffic	Reg. worst-case	Max traffic	Reg. worst-case	Max traffic	Reg. worst-case	Max traffic	Reg. worst-case
Portal emissions									
Benzene	580	0.04	29	0.02	29	0.000069	0.050	0.000034	0.050
Toluene	15000	0.08	62	0.04	62	0.000005	0.0041	0.000003	0.0041
Xylenes	7400	0.06	46	0.03	46	0.000008	0.0062	0.000004	0.0062
1,3-Butadiene	660	0.01	6.6	0.004	6.6	0.000015	0.010	0.000006	0.010
Formaldehyde	100	0.02	11	0.01	11	0.00020	0.11	0.00010	0.11
Acetaldehyde	470	0.01	6.8	0.004	6.8	0.000021	0.014	0.000009	0.014
					Total HI	**0.00032**	**0.19**	**0.00016**	**0.19**
					% change in HI with project	**-71%**	**NA**	**-76%**	**NA**
Ventilation outlet emissions									
Benzene	580	0.03	2.0	0.02	2.0	0.000052	0.0035	0.000034	0.0031
Toluene	15000	0.07	4.3	0.04	4.3	0.000005	0.00029	0.000003	0.00025
Xylenes	7400	0.06	3.2	0.03	3.2	0.000008	0.00044	0.000004	0.00038
1,3-Butadiene	660	0.01	0.46	0.004	0.46	0.000015	0.00070	0.000006	0.00063
Formaldehyde	100	0.02	0.76	0.01	0.76	0.00020	0.0076	0.00010	0.0079
Acetaldehyde	470	0.01	0.47	0.004	0.47	0.000021	0.010	0.000009	0.00089
					Total HI	**0.00030**	**0.014**	**0.00016**	**0.014**
					% change in HI with project	**-73%**	**NA**	**-76%**	**NA**
					Acceptable HI	**≤1**	**≤1**	**≤1**	**≤1**

* Maximum 1-hour average air concentrations based on the modelled 99.9th percentile concentration which is considered representative of the maximum plausible air concentration that may be present.

NA = not assessed as the regulatory worst-case scenario is an unrealistic maximum

Table 5-8: Assessment of chronic exposures – Typical traffic scenario

VOC assessed	Chronic air guideline (µg/m³)	Modelled maximum annual average air concentrations (µg/m³)				Calculated HI			
		2030		2040		2030		2040	
		Without project	With project	Without project	With project	Without project	With project	Without project	With project
Portal emissions									
Benzene	30	0.017	0.0037	0.0091	0.011	0.00056	0.00012	0.00030	0.00036
Toluene	5000	0.035	0.0078	0.019	0.023	0.0000071	0.0000016	0.0000038	0.0000045
Xylenes	220	0.026	0.0058	0.015	0.017	0.00012	0.000026	0.000068	0.000079
Formaldehyde	100	0.0073	0.0016	0.0046	0.0055	0.000073	0.000016	0.000046	0.000055
Acetaldehyde	9	0.0039	0.00085	0.0022	0.0025	0.00043	0.000094	0.00024	0.00028
					Total HI	**0.00063**	**0.00014**	**0.00036**	**0.00042**
					% change in HI with project		-78%		18%
Ventilation outlet emissions									
Benzene	30	0.017	0.0029	0.0091	0.0078	0.00056	0.00010	0.00030	0.00026
Toluene	5000	0.035	0.0062	0.019	0.017	0.0000071	0.0000012	0.0000038	0.0000033
Xylenes	220	0.026	0.0046	0.015	0.013	0.00012	0.000021	0.000068	0.000058
Formaldehyde	100	0.0073	0.0013	0.0046	0.0040	0.000073	0.000013	0.000046	0.000040
Acetaldehyde	9	0.0039	0.00068	0.0022	0.0019	0.00043	0.000075	0.00024	0.00021
					Total HI	**0.00063**	**0.00011**	**0.00036**	**0.00031**
					% change in HI with project		-83%		-14%
					Acceptable HI	**≤1**	**≤1**	**≤1**	**≤1**

Table 5-9: Assessment of carcinogenic risks – Typical traffic scenario

VOC assessed	Inhalation unit risk (µg/m³)	Modelled maximum annual average air concentrations (µg/m³)				Calculated incremental lifetime risk			
		2030		2040		2030		2040	
		Without project	With project	Without project	With project	Without project	With project	Without project	With project
Portal emissions									
Benzene	6×10^{-6}	0.017	0.0037	0.010	0.011	4.0×10^{-8}	8.8×10^{-9}	2.5×10^{-8}	2.8×10^{-9}
1,3-Butadiene	5×10^{-7}	0.0039	0.00085	0.0024	0.0025	7.7×10^{-10}	1.7×10^{-10}	4.8×10^{-10}	4.9×10^{-10}
PAHs*	0.087	0.000025	5.4×10^{-6}	0.000015	1.8×10^{-5}	8.6×10^{-7}	1.9×10^{-7}	5.4×10^{-7}	6.3×10^{-7}
					Total risk	**9×10^{-7}**	**2×10^{-7}**	**6×10^{-7}**	**7×10^{-7}**
DPM	3.4×10^{-5}	--	0.32	--	0.41	--	1×10^{-5}	--	1×10^{-5}
Ventilation outlet emissions									
Benzene	6×10^{-6}	0.017	0.0029	0.010	0.0078	4.0×10^{-8}	7.0×10^{-9}	2.5×10^{-8}	1.9×10^{-8}
1,3-Butadiene	5×10^{-7}	0.0039	0.00068	0.0024	0.0018	7.7×10^{-10}	1.4×10^{-10}	4.8×10^{-10}	3.6×10^{-10}
PAHs*	0.087	0.000025	4.3×10^{-6}	0.000015	1.3×10^{-5}	8.6×10^{-7}	1.5×10^{-7}	5.4×10^{-7}	4.7×10^{-7}
					Total risk	**9×10^{-7}**	**2×10^{-7}**	**6×10^{-7}**	**5×10^{-7}**
DPM	3.4×10^{-5}	--	0.043	--	0.047	--	1×10^{-6}	--	2×10^{-6}
					Acceptable risk	**$\leq 1 \times 10^{-5}$**	**$\leq 1 \times 10^{-5}$**	**$\leq 1 \times 10^{-5}$**	**$\leq 1 \times 10^{-5}$**
					Negligible risk	**$\leq 1 \times 10^{-6}$**	**$\leq 1 \times 10^{-6}$**	**$\leq 1 \times 10^{-6}$**	**$\leq 1 \times 10^{-6}$**

For the assessment of acute exposures to VOCs (**Table 5-6** and **Table 5-7**), the calculated HI associated with exposure to the maximum concentrations predicted is significantly lower than one for expected and peak traffic scenarios and all ventilation scenarios, with no significant difference in the calculated risks for the ventilation scenarios evaluated. For the regulatory worst-case scenario, the calculated HI is less than one for both ventilation options. On this basis, there are no acute risk issues in the local community associated with the project.

For the assessment of chronic exposures to VOCs (**Table 5-8**), the calculated HI associated with exposure to the maximum concentrations predicted is significantly lower than one for all the project scenarios. The calculated lifetime cancer risks (**Table 5-9**) associated with the maximum change in benzene, 1,3-butadiene and PAHs as benzo(a)pyrene TEQ are less than $1x10^{-6}$ in relation to all impacts associated with emissions from the project where either portal emissions or ventilation outlets are constructed.

In addition, the maximum calculated lifetime cancer risk associated with exposure to DPM are equal to $1x10^{-5}$ (considered acceptable) for portal emissions and $1x10^{-6}$ for ventilation outlet emissions (considered negligible). It is noted that where the more realistic emissions estimates are considered in the assessment of DPM, the risk would be lower. On this basis, the calculated carcinogenic risks are considered low and acceptable.

There are thus no chronic health risk issues of concern in the local community associated with air toxics or DPM from the project.

On the basis of the assessment undertaken, there are no acute or chronic health risk issues in the local community associated with volatile organic compounds or DPM from the project.

5.6 Assessment of health impacts – carbon monoxide

Motor vehicles are the dominant source of carbon monoxide in air (DECCW 2009). Carbon monoxide is produced during combustion when there is a limited supply of oxygen. This includes combustion engines in vehicles.

The sorts of effects that can be expected due to exposure to CO are those linked with carboxyhaemoglobin (COHb) in blood – i.e., where CO replaces oxygen in the blood preventing oxygen from being transported around the body. In addition, association between exposure to carbon monoxide and cardiovascular hospital admissions and mortality, especially in the elderly for cardiac failure, myocardial infarction and ischemic heart disease; and some birth outcomes (such as low birth weights) have been identified (NEPC 2010). The current NEPC air standards are consistent with health based guidelines currently available from the WHO (WHO 2005, 2010) and the USEPA (2011[2], specifically listed to be protective of exposures by sensitive populations including asthmatics, children and the elderly). On this basis, the current NEPC standards are considered appropriate for the assessment of potential health impacts associated with the project.

Guidelines are available from the NSW EPA (NSW EPA 2017) and NEPC (NEPC 2016, 2021) which indicate concentrations of carbon monoxide considered to be acceptable by national health authorities. These guidelines relate to short-term exposures to carbon monoxide, based on a 1-hour average and 8-hour average air concentration.

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[2] Review of the Primary National Ambient Air Quality Standards for Carbon Monoxide published by the USEPA in the Federal Register Volume 76, No. 169, 2011, available from: http://www.gpo.gov/fdsys/pkg/FR-2011-08-31/html/2011-21359.htm

Table 5-10 presents a comparison of the modelled maximum concentration of carbon monoxide in air (as a cumulative concentration from all sources) in the surrounding community with comparison against NEPC air guideline.

Table 5-10: Assessment of exposure to carbon monoxide

Scenario evaluated	Modelled concentration of carbon monoxide in air (µg/m^3)			
	Maximum 1 hour average		Maximum 8 hour average	
	2030	2040	2030	2040
Typical emissions scenario				
Portal emissions				
Without project	1,430	1,412	809	790
With project	1,404	1,420	775	792
Ventilation outlet emissions				
Without project	1,430	1,412	809	790
With project	1,404	1,405	775	791
Peak traffic scenarios				
Portal emissions				
Maximum traffic	1,404	1,401	776	773
Regulatory worst-case	29,800	29,800	6,136	6,136
Ventilation outlet emissions				
Maximum traffic	1,405	1,399	776	773
Regulatory worst-case	2,218	2,218	961	961
NEPC Air standard	**30,000**	**30,000**	**10,000**	**10,000**

For the typical traffic scenario and maximum traffic scenarios, all the concentrations of carbon monoxide presented in **Table 5-10** are substantially below the relevant health-based standards/guidelines listed at the base of the table.

In relation to the regulatory worst-case scenario, the results from this scenario are considered to be hypothetical, and the data indicates the maximum concentrations (particularly for the 1 hour average) have the potential for be significantly higher than for the typical and maximum traffic scenarios, however all concentrations predicted remain below the adopted NEPC standards.

The project would not change the existing health outcomes in relation to exposures in the community to carbon monoxide, either adversely or beneficially. The changes due to the operation of the project under typical or peak traffic scenarios, are not significant. No adverse health effects are expected in relation to exposures (acute and chronic) to carbon monoxide in the local area surrounding the project.

5.7 Assessment of health impacts – nitrogen dioxide

5.7.1 Approach

Nitrogen oxides (NOx) refer to a collection of highly reactive gases containing nitrogen and oxygen, most of which are colourless and odourless. Nitrogen oxide gases form when fuel is burnt including when residual waste is used as fuel. Motor vehicles, along with industrial, commercial and residential (e.g., gas heating or cooking) combustion sources, are primary producers of nitrogen oxides.

In greater NSW, on-road vehicles accounted for about 15% of emissions of nitrogen oxides and industrial facilities accounted for 53%. In Sydney, a greater contribution is derived from on-road vehicles (approximately 53%, predominantly from diesel engines) (Ewald et al. 2020; NSW EPA 2019).

In terms of health effects, nitrogen dioxide is the only oxide of nitrogen that may be of concern (WHO 2000a). Nitrogen dioxide is a colourless and tasteless gas with a sharp odour. Nitrogen dioxide can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. Exposure to elevated levels of nitrogen dioxide has also been associated with increased mortality, particularly related to respiratory disease, and with increased hospital admissions for asthma and heart disease patients (WHO 2013a). Asthmatics, the elderly and people with existing cardiovascular and respiratory disease are particularly susceptible to the effects of elevated nitrogen dioxide (Morgan, Broom & Jalaludin 2013; NEPC 2010). The health effects associated with exposure to nitrogen dioxide depend on the duration of exposure as well as the concentration.

Guidelines are available from NSW EPA (NSW EPA 2017) and NEPC (NEPC 2016, 2021) which indicate concentrations of nitrogen dioxide considered to be acceptable by national health authorities. In May 2021, the national guidelines for nitrogen dioxide in the air quality NEPM were changed (NEPC 2021). This update resulted in lower air guidelines for nitrogen dioxide based on consideration of the current health evidence and more stringent guidelines in other leading countries. These lower air guidelines incorporate a greater margin of safety than in the previous NEPC (2016) guidance and have also been considered in this assessment.

These guidelines are based on protection from adverse health effects following both short term (acute) and longer term (chronic) exposure for all members of the population including sensitive populations like asthmatics, children and the elderly.

When reviewing the available literature on the health effects associated with exposure to nitrogen dioxide it is important to consider the following:

- whether the evidence suggests that associations between exposure to nitrogen dioxide concentrations and effects on health are causal. The most current review undertaken by the USEPA (USEPA 2015) specifically evaluated evidence of causation. The review identified that a causal relationship existed for respiratory effects (for short-term exposure with long term exposures also likely to be causal). All other associations related to exposure to nitrogen dioxide (specifically cardiovascular effects, mortality and cancer) were considered to be suggestive
- whether the reported associations are distinct from, and additional to, those reported and assessed for exposure to particulate matter. Co-exposures to nitrogen dioxide and particulate matter complicates review and assessment of many of the epidemiology studies

as both these air pollutants occur together in urban areas. There is sufficient evidence (epidemiological and mechanistic) to suggest that some of the health effect associations identified relate to exposure to nitrogen dioxide after adjustment/correction for co-exposures with particulate matter (COMEAP 2015)

- whether the assessment of potential health effects associated with exposure to different levels of nitrogen dioxide can be undertaken on the basis of existing guidelines, or whether specific risk calculations are required to be undertaken. The current guidelines in Australia for the assessment of nitrogen dioxide in air relate to cumulative (total) exposures and adopt criteria that are considered to be protective of short and long term exposures. It is thus relevant that these guidelines be considered in this assessment
- in addition, the current standards relate to regional air quality, not localised sources and hence use of such standards for the assessment of localised exposures is of limited value.

For these situations, it is relevant to also evaluate the impact on community health of the change in nitrogen dioxide concentration in the local community using appropriate risk calculations. For the conduct of risk assessments in relation to exposure to nitrogen dioxide, the WHO (WHO 2013a) identified that the strongest evidence of health effects related to respiratory hospitalisations and to a lesser extent mortality (associated with short-term exposures) and recommend that these health endpoints should be considered in any core assessment of health impacts associated with exposure.

On the basis of the above, potential health effects associated with exposure to nitrogen dioxide have been undertaken on the basis of both comparison with guidelines (assessing cumulative exposures) and an assessment of incremental impacts on health (associated with changes in air quality from the project).

5.7.2 Assessment of cumulative exposures

Table **5-11** summarises the maximum predicted cumulative 1-hour average and annual average concentrations of nitrogen dioxide for the emissions scenarios evaluated in this assessment. These concentrations have been compared with both the NEPC (2016) guideline, which is included in NSW EPA (2017) guidance and adopted in Appendix E (Technical report - Air Quality) of the EIS, and the NEPC (2021) guideline.

Table 5-11: Review of potential acute and chronic health impacts – nitrogen dioxide

Scenario	Maximum 1-hour average concentration (µg/m³)		Maximum annual average concentration (µg/m³)	
	2030	2040	2030	2040
Typical traffic scenario				
Portal emissions				
Without project	144.5	144.5	53.3	33.5
With project	142.3	131.8	22.0	15.6
Ventilation outlet emissions				
Without project	144.5	144.5	53.3	33.5
With project	136.6	130.9	17.4	14.6
Peak traffic scenarios				
Portal emissions				
Maximum traffic	134.9	131.1	NA	NA
Regulatory worst-case	157.5	157.5	NA	NA
Ventilation outlet emissions				
Maximum traffic	132.9	126.4	NA	NA
Regulatory worst-case	144.4	144.4	NA	NA
Relevant health based standards				
NEPC (2016) and NSW EPA (2017)	246		62	
NEPC (2021)	62		28	

Shaded cells – predicted air concentrations that exceed a health based standard (as relevant to the colour of the shading)

NA = Assessment of chronic exposures to nitrogen dioxide for the peak traffic scenarios is not applicable as these scenarios may only occur on occasion (few days per year) or may not occur (as may be the case for the regulatory worst-case)

Where the NEPC (2016) and NSW EPA (2017) standards are utilised, there are no exceedances predicted for nitrogen dioxide in air, relevant to the assessment of acute and chronic exposures. This relates to all traffic and emissions scenarios evaluated. These guidelines are based on the protection of adverse health effects in the community.

However, where the lower standards in the NEPM (2021) are utilised, the maximum predicted 1-hour average concentrations of nitrogen dioxide in air (for all traffic and emission scenarios), relevant to the assessment of acute inhalation exposures exceed the guideline. With the project, the maximum 1-hour average air concentrations are lower, indicating that the operation of the project provides a benefit in reducing peak short-term impacts of nitrogen dioxide in the community. Further, without the project the maximum predicted concentrations of nitrogen dioxide in air are predicted to exceed the chronic (annual average) air guideline. The project would therefore reduce nitrogen dioxide exposures and result in compliance with the NEPC (2021) chronic air guideline. The predicted annual average air concentrations predicted with the project in 2030 and 2040 (regardless of the emissions design) are essentially the same as or lower than the cut-off for long-term health impacts determined in the WHO Health risks of air pollution in Europe (HRAPIE) (WHO 2013b) study of 20 µg/m³ (NEPC 2019). Where this is the case there are no health risk issues of concern in relation to chronic exposures that would warrant further assessment.

While there are some exceedances of the NEPC (2021) guideline, no significant adverse health effects are expected in the community, noting that the project reduces short and long-term exposures to nitrogen dioxide in the community. Further assessment of potential changes in nitrogen dioxide exposure on community health are presented in the following section.

5.7.3 Assessment of incremental exposures

The evidence base supports quantification of effects of chronic and short-term (acute) exposures, using the same averaging time as in the relevant studies. In relation to chronic health effects, the construction of the project would result in annual average concentrations below the threshold for effects and hence no further assessment has been undertaken.

In relation to short-term exposures, the strongest evidence is for respiratory effects particularly for people aged 65 years and older, particularly exacerbation of asthma (particularly within children), with some support also for all-cause mortality. These health endpoints have been evaluated in relation to changes in nitrogen dioxide concentrations in air associated with the project.

Table 5-12 summarises the health endpoints considered in this assessment, the β coefficient relevant to the calculation of a relative risk (refer to **Annexure A** for details on the calculation of a β coefficient from published studies). The coefficients adopted for the assessment of impacts on mortality and asthma emergency department admissions are derived from the detailed assessment undertaken for the current review (NEPC 2019) of health impacts of air pollution for the NEPC (2021) revision and are considered to be current and robust.

Table 5-12: Adopted exposure-response relationships for assessment of changes in nitrogen dioxide concentrations

Health endpoint	Exposure period	Age group	Adopted β coefficient (also as %) for 1 $\mu g/m^3$ increase in NO_2	Reference
Mortality, all causes	Short-term (1-hour)	All ages	0.0006 (0.06%)	Relationship adopted from the WHO (WHO 2013b) review, as adopted in the NEPC revision (NEPC 2019)
Mortality, respiratory	Short-term	All ages*	0.00426 (0.43%)	Relationship derived for from modelling undertaken for 5 cities in Australia and 1 day lag (EPHC 2010; Golder 2013)
Asthma emergency department admissions	Short-term (24-hour)	1–14 years	0.00115 (0.12%)	Relationship established from review conducted on Australian children (Sydney) for the period 1997 to 2001 (Golder 2013; Jalaludin et al. 2008), as adopted in the NEPC revision (NEPC 2019)

* Relationships established for all ages, including young children and the elderly

As discussed in **Section 5.1**, the assessment of health impacts associated with nitrogen dioxide has considered population impacts as well as localised impacts.

Population health impacts

Table 5-13 presents the calculated population health risks and incidence (i.e., increase in the number of cases) associated with changes in emissions to air where the design relates to portal emissions or ventilation outlets, as well as emissions from the redistribution of vehicles on key surface roads within the study area (also refer to **Figure 5-2** and **Figure 5-3**) for illustration of the redistribution of impacts for Blackheath and Little Hartley).

The change in incidence across the population for each health indicator relevant to changes in nitrogen dioxide exposures in the local community (for the population exposed) has been calculated on the basis of the following:

- The relative risk has been calculated for an annual average incremental change in concentrations (i.e., with project minus without project). The annual average change for all individual receptors modelled has been used as this reflects all residential properties located in the study area and given the small size of the population adopting the average change is appropriate.
- A change in the number of cases associated with the change in nitrogen dioxide impact evaluated in the population within the study area has been calculated (refer to **Annexure A** for details on the methodology). The calculation is undertaken utilising the baseline incidence data relevant for the endpoint considered (refer to **Table 4-4**) and the population present for the study area (assuming the average percentage of age groups for all suburbs in the study area) (refer to **Table 4-2**).

Calculations relevant to the characterisation of risks associated with changes in nitrogen dioxide concentrations in the community are presented in **Annexure D**.

Table 5-13: Calculated population health impacts of changes in nitrogen dioxide for the project

Scenario evaluated	Population risk (for health endpoints evaluated)			Change in the number of cases (people in population per year) (for health endpoints)		
	Mortality – all causes (all ages)	Mortality – respiratory (all ages)	Asthma ED admissions (1-14 years)	Mortality – all causes (all ages)	Mortality – respiratory (all ages)	Asthma ED admissions (1-14 years)
Expected traffic scenario						
Portal emissions						
2030	-8×10^{-6}	-6×10^{-6}	-3×10^{-5}	-0.02	-0.01	-0.01
2040	-3×10^{-5}	-3×10^{-5}	-1×10^{-5}	-0.006	-0.003	-0.005
Ventilation outlet emissions						
2030	-8×10^{-6}	-6×10^{-6}	-3×10^{-5}	-0.01	-0.007	-0.01
2040	-4×10^{-6}	-3×10^{-6}	-2×10^{-5}	-0.006	-0.004	-0.006

The calculated impacts presented in **Table 5-13** indicates that for the population evaluated in the study area, exposures to nitrogen dioxide would decrease (decreased population risk and health incidence) with the project, regardless of whether the design utilised portal emissions or ventilation outlet emissions. This is consistent with the predicted reduction in total (background plus project) nitrogen dioxide concentrations in the study area (refer to **Table 5-11**). These reductions in nitrogen dioxide indicate the project would provide some health benefit to the population.

Localised health impacts

Table 5-14 presents the change in risk associated with the maximum localised change in nitrogen dioxide concentrations as a result of emissions to air from portals (where portal emissions are considered) or the ventilation facilities as well as the redistribution of traffic on surface roads. This redistribution of nitrogen dioxide concentrations is illustrated in **Figure 5-2** and **Figure 5-3** that shows the change (or impact) in annual average nitrogen dioxide concentrations for Blackheath and Little Hartley, for each ventilation option. These figures illustrate the reduction in nitrogen dioxide concentrations adjacent to existing surface roads where traffic volumes are predicted to decrease, with some localised increases adjacent to the ventilation outlet to portals (which includes the locations of impacts assessed in **Table 5-14**). As shown in these figures, the locations of maximum increases in nitrogen dioxide are in areas where there are no sensitive receptors.

As discussed in **Section 5.1** the assessment of localised health risks has been undertaken to assist in evaluating the significance of the maximum impacts and inform the need for risk management.

Table 5-14: Calculated maximum individual risk from changes in nitrogen dioxide for the project

Scenario evaluated	Maximum individual risk (for health endpoints evaluated)		
	Mortality – all causes (all ages)	Mortality – respiratory (all ages)	Asthma ED admissions (1-14 years)
Expected traffic scenario			
Portal emissions			
2030	6×10^{-6}	4×10^{-6}	2×10^{-5}
2040	3×10^{-6}	3×10^{-6}	1×10^{-5}
Ventilation outlet emissions			
2030	3×10^{-6}	2×10^{-6}	1×10^{-5}
2040	6×10^{-6}	4×10^{-6}	2×10^{-5}

All calculated individual risks are less than the risk management action level of 1×10^{-4}, indicating that maximum changes in nitrogen dioxide in the local community as a result of the project are considered to be low and acceptable. This outcome is the same irrespective of whether the project design implements portal emissions or emissions from ventilation outlets.

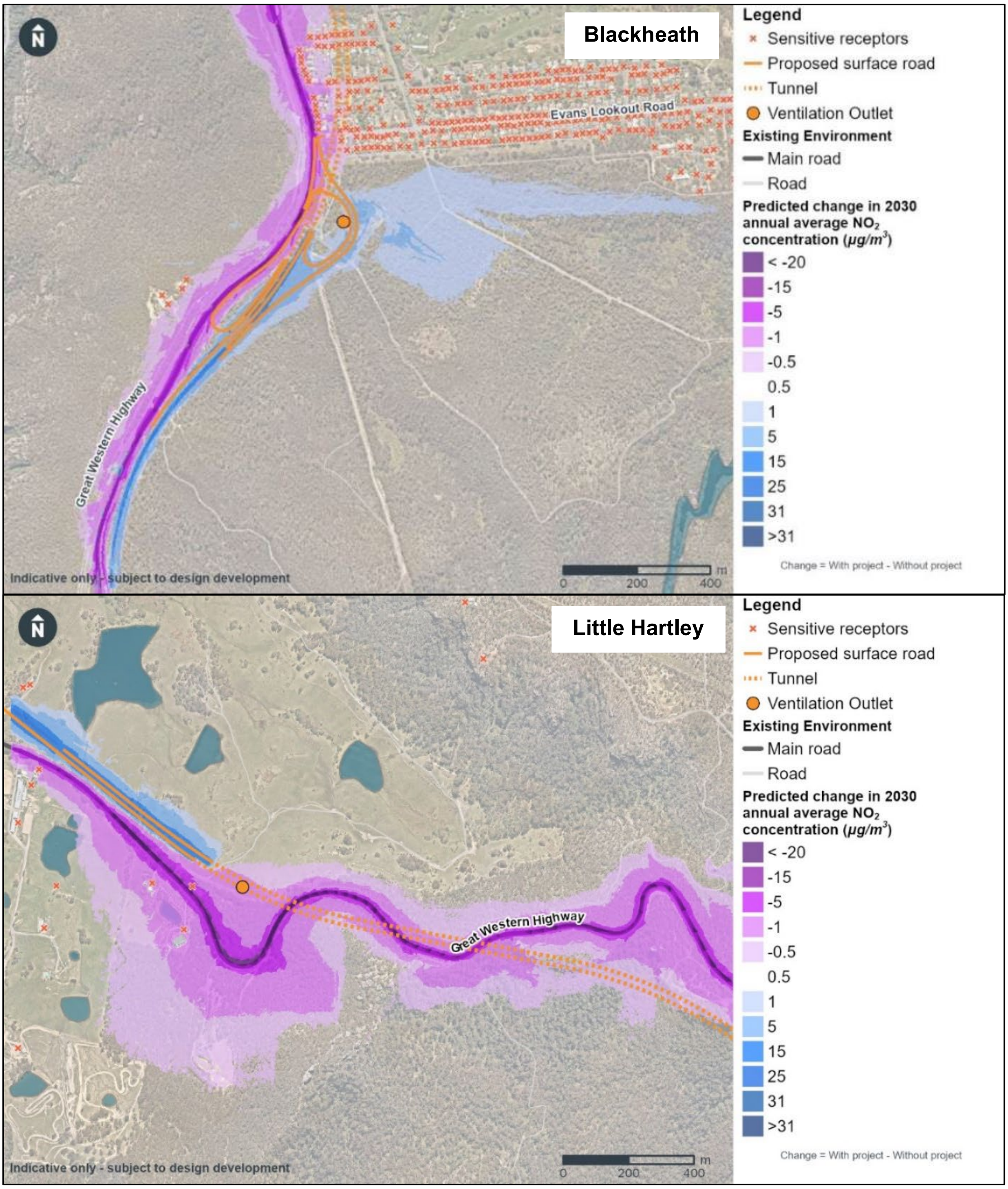
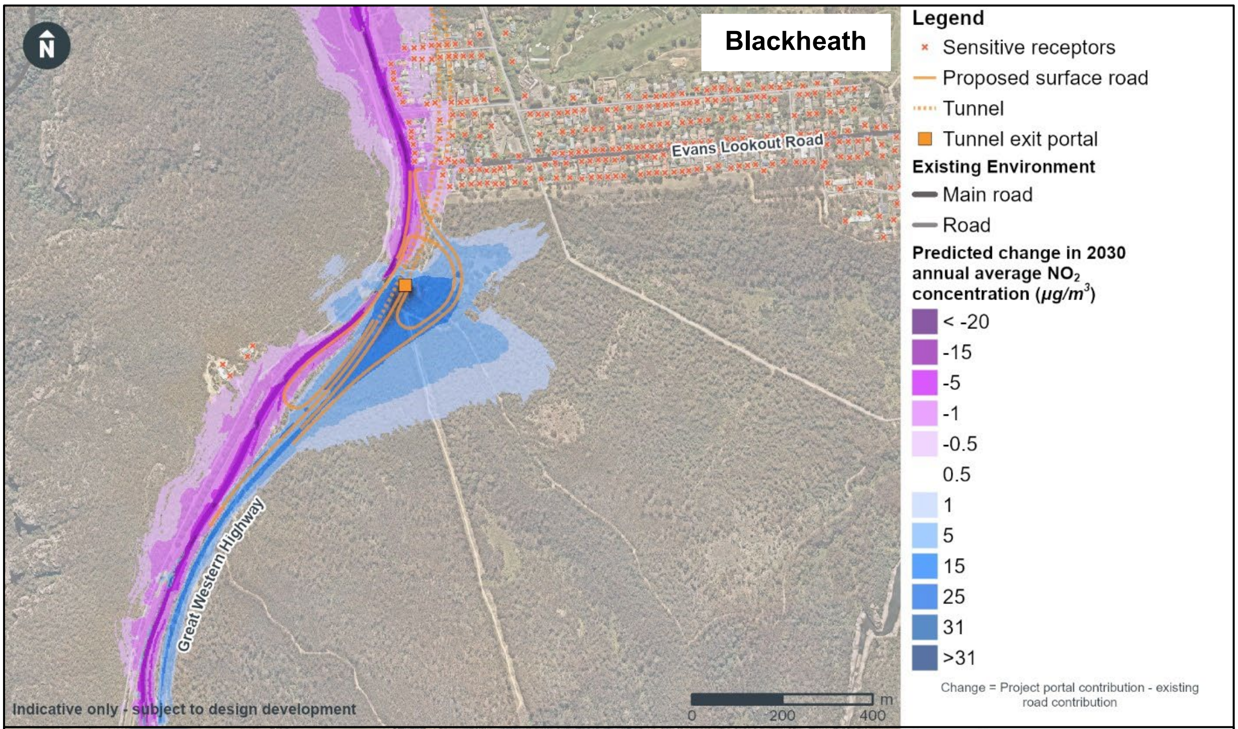


Figure 5-2: Annual average change in NO_2 concentration for ventilation outlet option for 2030 (from Appendix E (Technical report - Air quality) of the EIS)



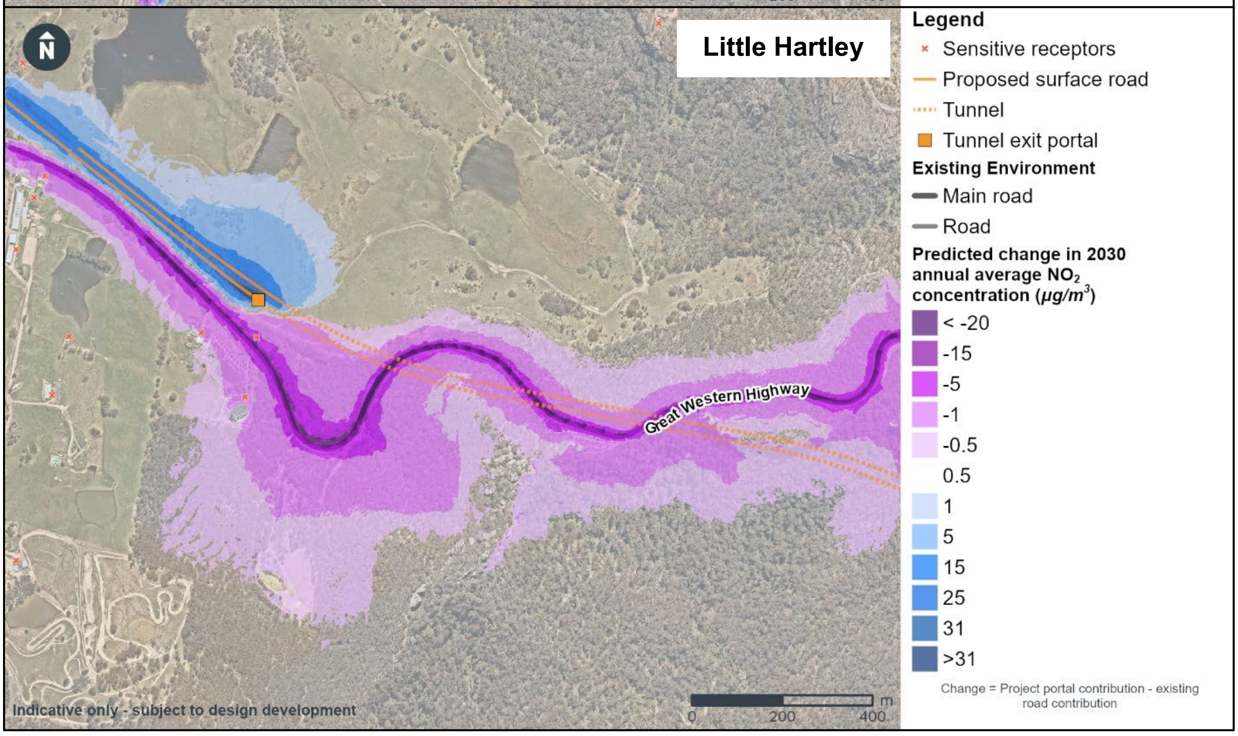


Figure 5-3: Annual average change in NO_2 concentration for portal outlet option for 2030 (from Appendix E (Technical report - Air quality) of the EIS)

Maximum traffic and regulatory worst-case scenarios

The maximum traffic scenario relates to a higher level of traffic in the tunnel during selected times of the year. This scenario reflects likely peak emissions from the project, which may occur only on a few days of the year. The calculated impacts presented in **Table 5-13** and **Table 5-14** are sufficiently low such that any increase in annual average concentrations that may occur as a result of including impacts from the maximum traffic scenario over approximately ten percent of the year does not change the outcomes presented for population and individual risks.

The regulatory worst-case scenario assumes the tunnel is full of vehicles at all times of the day, every day, which is unrealistic. The scenario may reflect a short-duration issue such as an accident or breakdown that may result in the tunnel being significantly congested for a short period of time such as a few hours. As a result, the impacts predicted for this scenario are higher than for the typical traffic and maximum traffic scenarios. Where such an event occurs for a period of 4 hours, once every two weeks of the year, the change in annual average is small, and the increase in the calculated population and individual risks is also small. Overall, there would be no change in the outcomes, in terms of population and individual risk presented above.

The project would result in a decrease in the level of exposure to nitrogen dioxide in the population within the study area that may have some long-term health benefits. The project design with either portal or ventilation outlet emissions would result in localised impacts that would are considered low and acceptable.

5.8 Assessment of health impacts – particulates

5.8.1 Particle size

Particulate matter is a widespread air pollutant with a mixture of physical and chemical characteristics that vary by location (and source). Unlike many other pollutants, particulates comprise a broad class of diverse materials and substances, with varying morphological, chemical, physical and thermodynamic properties, with sizes that vary from less than 0.005 microns to greater than 100 microns. Particulates can be derived from natural sources such as crustal dust (soil), pollen and moulds, and other sources that include combustion and industrial processes. Secondary particulate matter is formed via atmospheric reactions of primary gaseous emissions. The gases that are the most significant contributors to secondary particulates include nitrogen oxides, ammonia, sulfur oxides, and certain organic gases (derived from vehicle exhaust, combustion sources, agricultural, industrial and biogenic emissions).

Numerous epidemiological studies[3] have reported significant positive associations between particulate air pollution and adverse health outcomes, particularly mortality as well as a range of adverse cardiovascular and respiratory effects.

The potential for particulate matter to result in adverse health effects is dependent on the size and composition of the particulate matter. The common measures of particulate matter that are considered in the assessment of air quality and health risks are:

- total suspended particulates (TSP): This refers to all particulates with an equivalent aerodynamic particle[4] size below approximately 50 microns in diameter[5]. It is a fairly gross indicator of the presence of dust with a wide range of sizes. Larger particles (termed 'inspirable', comprise particles around 10 microns and larger) are more of a nuisance as they would deposit out of the air (measured as deposited dust) close to the source and, if inhaled, are mostly trapped in the upper respiratory system[6] and do not reach the lungs. Finer particles (smaller than 10 microns, termed 'respirable') tend to be transported further from the source and are of more concern with respect to human health as these particles can penetrate into the lungs (see following point). Not all of the dust characterised as total suspended particulates is thus relevant for the assessment of health impacts, and total suspended particulates as a measure of impact, has not been further evaluated in this assessment. The assessment has only focused on particulates of a size where significant associations have been identified between exposure and adverse health effects
- PM_{10} (particulate matter below 10 microns in diameter, µm), $PM_{2.5}$ (particulate matter below 2.5 µm in diameter) and PM_1 (particulate matter below one µm in diameter, often termed very fine particles) and ultrafines (particulate matter below 0.1 µm in diameter), as illustrated in **Figure 5-4.** These particles are small and have the potential to penetrate beyond the body's natural clearance mechanisms of cilia and mucous in the nose and upper respiratory system, with smaller particles able to further penetrate into the lower respiratory tract[7] and lungs. Once in the lungs adverse health effects may result (OEHHA 2002).

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[3] Epidemiology is the study of diseases in populations. Epidemiological evidence can only show that this risk factor is associated (correlated) with a higher incidence of disease in the population exposed to that risk factor. The higher the correlation the more certain the association. Causation (i.e. that a specific risk factor actually causes a disease) cannot be proven with only epidemiological studies. For causation to be determined a range of other studies need to be considered in conjunction with the epidemiology studies.

[4] The term equivalent aerodynamic particle is used to reference the particle to a particle of spherical shape and particle of density one gram per cubic metre.

[5] The size, diameter, of dust particles is measured in micrometers (microns).

[6] The upper respiratory tract comprises the mouth, nose, throat and trachea. Larger particles are mostly trapped by the cilia and mucosa and swept to the back of the throat and swallowed.

[7] The lower respiratory tract comprises the smaller bronchioles and alveoli, the area of the lungs where gaseous exchange takes place. The alveoli have a very large surface area and absorption of gases occurs rapidly with subsequent transport to the blood and the rest of the body. Small particles can reach these areas, be dissolved by fluids and absorbed.

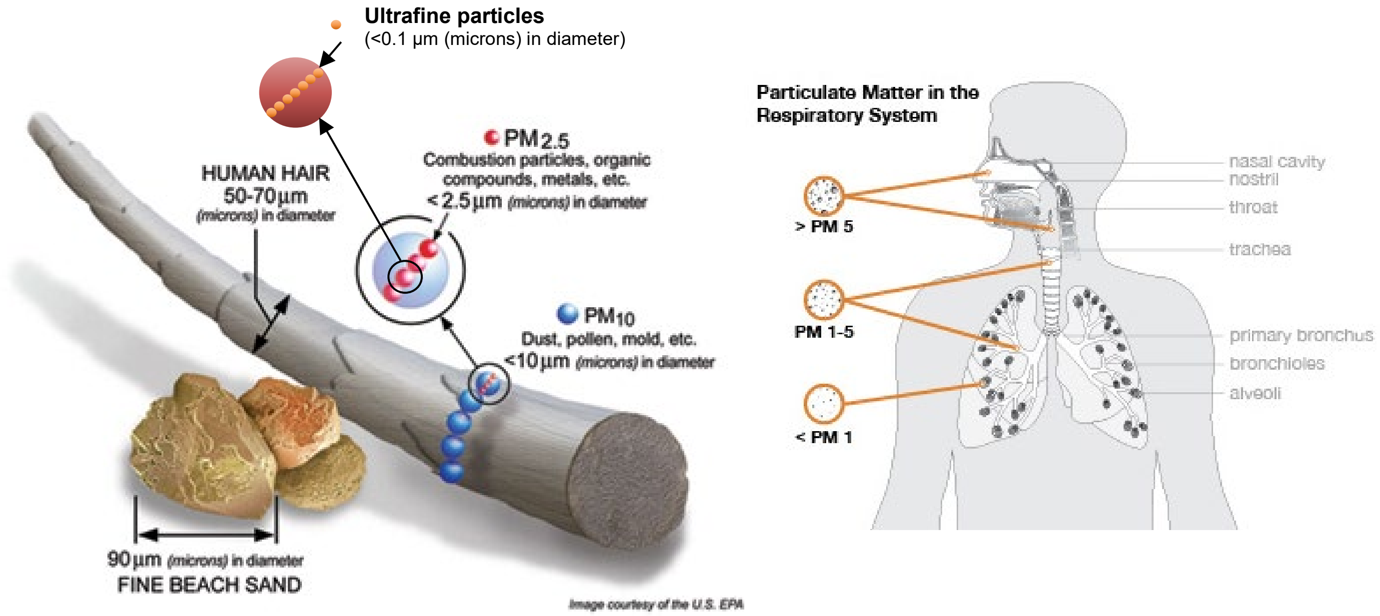


Figure 5-4: Illustrative representation of particle sizes and penetration into the lungs

Evaluation of size alone as a single factor in determining the potential for particulate toxicity is difficult since the potential health effects are not independent of chemical composition. There are certain particulate size fractions that tend to contain certain chemical components. Metals are commonly found attached to fine particulates (less than $PM_{2.5}$) while crustal materials (like soil) are usually larger and are present as PM_{10} or larger. In addition, different sources of particulates have the potential to result in the presence of other pollutants in addition to particulate matter. For example, combustion sources, prevalent in urban areas, result in the emission of particulate matter (more dominated by $PM_{2.5}$) as well as gaseous pollutants (such as nitrogen dioxide and carbon monoxide). This results in what is referred to as co-exposure and is an issue that has to be accounted for when evaluating studies that come from studying health effects in large populations exposed to pollution from many sources (as is the case in urban air).

Where co-exposure is accounted for the available science supports that exposure to fine particulate matter (less than 2.5 µm, $PM_{2.5}$) is associated (and shown to be causal in some cases) with health impacts in the community (USEPA 2012). A more limited body of evidence suggests an association between exposure to larger particles, PM_{10} and adverse health effects (USEPA 2009a, 2018; WHO 2003).

It is noted that when assessing potential health impacts associated with changes in particulate matter concentrations the studies relied upon for establishing associations (between changes in concentrations in air and health effects) are large epidemiological studies. These studies relate changes in health indicators with changes in measured concentrations of particulate matter. As a result, the particle size fractions addressed in these studies relate to the fractions measured in the urban air environment studies.

In relation to measuring particulate matter in urban air, the following should be noted:

- the measurement of particulate matter in urban air most commonly reports PM_{10}. This is the concentration of particulate matter less than or equal to 10 µm in diameter (and includes the smaller fractions of $PM_{2.5}$ and very fine particles). The measurement techniques for PM_{10} are well established and provide stable, robust, verifiable data that is considered to be consistently reported across all countries. This means this data on PM_{10} collected in different parts of a city, in different parts of a country and by different countries can be compared against each other. This is the key reason why many of the epidemiological studies have looked at associations between PM_{10} and various health effects
- the measurement of $PM_{2.5}$ is becoming more common in urban environments. This is the concentration of particulate matter less than or equal to 2.5 µm in diameter (and includes the smaller fractions of very fine particles and ultrafines). The measurement techniques used for $PM_{2.5}$ are less well established resulting in data that varies depending on the type of equipment used and how it is set-up and maintained. Due to either a lack of monitoring data or the inconsistency of monitoring data some epidemiology studies have assessed associations between $PM_{2.5}$ and health effects by using PM_{10} data and assuming that a certain percentage of PM_{10} comprises $PM_{2.5}$. Some studies have directly used measurements of $PM_{2.5}$ in urban air. Even where these measurement issues are considered, the studies still clearly show strong relationships between changes in $PM_{2.5}$ concentrations and health effects
- the measurement of very fine and ultrafine particles is difficult (using equipment that is less robust/stable and provides variable data) and has not been undertaken in most urban air environments. As a result, there are no robust epidemiological studies that relate changes in ultrafine particle levels and health effects that can be used in a risk assessment. There is sufficient data available to confirm that motor vehicles are a key source of ultrafine particles. Available studies in animals and humans have identified a range of adverse health effects associated with exposure to ultrafine particulates, however the studies do not show that short-term exposure to ultrafine particulates have effects that are significantly different from those associated with exposure to $PM_{2.5}$ (HEI 2013).

When assessing health impacts from fine particulates, the robust associations of effects (that are based on large epidemiology studies primarily from the US and Europe) have been determined on the basis of $PM_{2.5}$, which is what is commonly measured in urban air. No robust associations (that can be used in a quantitative assessment) are available for PM_1 and the current science is inconclusive in relation to ultrafine particulates. The associations developed for $PM_{2.5}$ would include a significant contribution from PM_1 (as $PM_{2.5}$ comprises a significant proportion of PM_1) and so health effects observed for PM_1 would be captured in the studies that have been conducted on the basis of $PM_{2.5}$. It is important that the quantitative evaluation of potential health impacts adopts robust health effects associations and utilises particulate matter measures that are collected in the urban air environment. The further assessment of exposure to fine particulate matter has thus focused on particulates reported/evaluated as $PM_{2.5}$.

5.8.2 Health effects

Adverse health effects associated with exposure to particulate matter have been well studied and reviewed by Australian and International agencies. Most of the studies and reviews have focused on population-based epidemiological studies in large urban areas in North America, Europe and Australia, where there have been clear associations determined between health effects and exposure to $PM_{2.5}$ and to a lesser extent, PM_{10}. These studies are complemented by findings from other key investigations conducted in relation to: the characteristics of inhaled particles; deposition and clearance of particles in the respiratory tract; animal and cellular toxicity studies; and studies on inhalation toxicity by human volunteers (NEPC 2010).

Particulate matter has been linked to adverse health effects after both short-term exposure (days to weeks) and long-term exposure (months to years). The health effects associated with exposure to particulate matter vary widely (with the respiratory and cardiovascular systems most affected) and include mortality and morbidity effects.

In relation to mortality, for short-term exposures in a population this relates to the increase in the number of deaths due to existing (underlying) respiratory or cardiovascular disease; for long-term exposures in a population this relates to mortality rates over a lifetime, where long-term exposure is considered to accelerate the progression of disease or even initiate disease.

In relation to morbidity effects, this refers to a wide range of health indicators used to define illness that have been associated with (or caused by) exposure to particulate matter. In relation to exposure to particulate matter, effects are primarily related to the respiratory and cardiovascular system and include (Morawska, Moore & Ristovski 2004; USEPA 2009a, 2018):

- aggravation of existing respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits)
- changes in cardiovascular risk factors such as blood pressure
- changes in lung function and increased respiratory symptoms (including asthma)
- changes to lung tissues and structure
- altered respiratory defence mechanisms.

The most recent review of the available studies (USEPA 2018) have also indicated that effects on the nervous system and carcinogenic effects are likely to have a causal relationship with long-term exposures to $PM_{2.5}$. IARC (2013) has classified particulate matter as carcinogenic to humans based on data relevant to lung cancer.

These effects are commonly used as measures of population exposure to particulate matter in community epidemiological studies (from which most of the available data in relation to health effects is derived) and are more often grouped (through the use of hospital codes) into the general categories of cardiovascular morbidity/effects and respiratory morbidity/effects. The available studies provide evidence for increased susceptibility for various populations, particularly older populations, children and those with underlying health conditions (USEPA 2009a).

There is consensus in the available studies and detailed reviews that exposure to fine particulates, $PM_{2.5}$, is associated with (and causal to) cardiovascular and respiratory effects and mortality (all causes) (USEPA 2012). While similar relationships have also been determined for PM_{10}, the supporting studies do not show relationships as clear as shown with $PM_{2.5}$ (USEPA 2012).

There are a number of studies that have been undertaken where other health effects have been evaluated. These studies have a large degree of uncertainty or a limited examination of the relationship and are generally only considered to be suggestive or inadequate (in some cases) of an association with exposure to $PM_{2.5}$ (USEPA 2018). This includes long term exposures and metabolic effects, male and female reproduction and fertility, pregnancy and birth outcomes; and short term exposures and nervous system effects (USEPA 2018).

In relation to the key health endpoints relevant to evaluating exposures to $PM_{2.5}$, there are some associated health measures or endpoints where the exposure-response relationships are not as string or robust as those for the key health endpoints and are considered to be a subset of the key health endpoints. This includes mortality (for different age groups), chronic bronchitis, medication use by adults and children with asthma, respiratory symptoms (including cough), restricted work days, work days lost, school absence and restricted activity days (Anderson et al. 2004; EC 2011b; Ostro 2004; WHO 2006b).

5.8.3 Approach to the assessment of particulate exposures

In relation to the assessment of exposures to particulate matter there is sufficient evidence to demonstrate that there is an association between exposure to $PM_{2.5}$ (and to a lesser extent PM_{10}) and effects on health that are causal.

The available evidence does not suggest a threshold below which health effects do not occur. Accordingly, there are likely to be health effects associated with background levels of $PM_{2.5}$ and PM_{10}, even where the concentrations are below the current guidelines. Standards and goals are currently available for the assessment of $PM_{2.5}$ and PM_{10} in Australia (NEPC 2021). These standards and goals are not based on a defined level of risk that has been determined to be acceptable, rather they are based on balancing the potential risks due to background and urban sources to lower impacts on health in a practical way.

The air quality standards and goals relate to average or regional exposures by populations from all sources, not to localised ‘hot-spot’ areas such as locations near industry, busy roads or mining. They are intended to be compared against ambient air monitoring data collected from appropriately sited regional monitoring stations. In some cases, there may be local sources (including busy roadways and industry) that result in background levels of PM_{10} and $PM_{2.5}$ that are close to, equal to, or in exceedance of, the air quality standards and goals. Where impacts are being evaluated from a local source it is important to not only consider cumulative impacts associated with the project (undertaken using the current air quality goals) but also evaluate the impact of changes in air quality within the local community.

This assessment has therefore been undertaken to consider both cumulative exposure impacts (refer to **Section 5.8.4**) and incremental exposure impacts associated with changes in $PM_{2.5}$ and PM_{10} concentrations that are associated with the project (refer to **Section 5.8.5**). Incremental changes are those due to the project alone while cumulative changes are those where background air quality in addition to those due to the project alone are considered.

5.8.4 Assessment of cumulative exposures

The assessment of cumulative exposures to $PM_{2.5}$ and PM_{10} is based on a comparison of the cumulative concentrations predicted with the current air quality standards and goals presented in the National Environment Protection Council (NEPC) (Ambient Air Quality) Measure (NEPM) (NEPC 2021). These standards are total concentrations in ambient air, within the community, that are based on the most current science in relation to health effects. Assessment of compliance against the NEPM is included in Appendix E (Technical report - Air Quality) of the EIS. The most current standards and goals, based on the protection of community health presented by the NEPC, have been further considered in this health impact assessment report.

In relation to the current NEPM PM_{10} standard, the following is noted (NEPC 1998, 2010, 2014, 2016):

- the standard was derived through a review of appropriate health studies by a technical review panel of the NEPC where short-term exposure-response relationships for PM_{10} and mortality and morbidity health endpoints were considered
- mortality health impacts were identified as the most significant and were the primary basis for the development of the standard
- on the basis of the available data for key air sheds in Australia, the criterion of 50 micrograms per cubic metre was based on analysis of the number of premature deaths that would be avoided and associated cost savings to the health system (using data from the US). The development of the standard is not based on any acceptable level of risk
- the assessment undertaken considered exposures and issues relevant to urban air environments that are expected to also be managed through the PM_{10} standard. These issues included emissions from vehicles and wood heaters.

A similar approach has been adopted by NEPC (Burgers & Walsh 2002; NEPC 2002, 2014) in relation to the derivation of the $PM_{2.5}$ air quality standards, with specific studies related to $PM_{2.5}$ and mortality and morbidity indicators considered. Goals for lower $PM_{2.5}$ standards to be met by 2025 are also outlined by NEPC (NEPC 2016, 2021).

Table 5-15 summarises the maximum predicted cumulative 24-hour average and annual average concentrations of $PM_{2.5}$ and PM_{10} for the emissions scenarios evaluated in this assessment. These concentrations have been compared with the NEPC (2021) standards and goals.

Table 5-15: Review of potential acute and chronic health impacts – Particulates

Scenario	Maximum 24-hour average concentration (µg/m³)		Maximum annual average concentration (µg/m³)	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Typical traffic scenario				
Portal emissions				
2030				
Without project	20.7	28.7	6.6	10.5
With project	18.6	25.5	5.7	9.2
2040				
Without project	20.1	28.2	6.3	10.3
With project	18.6	25.5	5.8	9.2
Ventilation outlet emissions				
2030				
Without project	20.7	28.7	6.6	10.5
With project	18.1	25.0	5.4	8.8
2040				

Scenario	Maximum 24-hour average concentration (µg/m³)		Maximum annual average concentration (µg/m³)	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Without project	20.1	28.2	6.3	10.3
With project	18.1	25.0	5.4	8.8
Peak traffic scenarios				
Portal emissions				
2030				
Maximum traffic	18.3	25.2	NA	NA
Regulatory worst-case	NA	49.7	NA	NA
2040				
Maximum traffic	18.4	25.4	NA	NA
Regulatory worst-case	NA	49.7	NA	NA
Ventilation outlet emissions				
2030				
Maximum traffic	18.1	24.9	NA	NA
Regulatory worst-case	NA	27.0	NA	NA
2040				
Maximum traffic	18.1	24.9	NA	NA
Regulatory worst-case	NA	27.0	NA	NA
Relevant health based standards				
NEPC standard (2021)	25	50	8	25
NEPC goal for 2025 (2021)	20	--	7	--

Shaded cells – predicted air concentrations that exceed a health based standard (as relevant to the colour of the shading)

NA = Assessment of chronic exposures for the peak traffic scenarios is not applicable as these scenarios may only occur on occasion (few days per year) or may not occur (as may be the case for the regulatory worst-case)

Review of **Table 5-15** indicates the following:

- without the project maximum 24-hour average concentrations of $PM_{2.5}$ have the potential to just exceed the NEPC goal of 20 µg/m³ for the year 2025, however with the project total concentrations of $PM_{2.5}$ are lower and would comply with the NEPC goal, regardless of whether the project adopts portal emissions or ventilation outlet emissions
- maximum 24-hour average PM_{10} concentrations meet the NEPC standard, noting that concentrations would be lower with the project, regardless of whether the project adopts portal emissions or ventilation outlet emissions
- annual average concentrations of $PM_{2.5}$ and PM_{10} meet the NEPC standards and goals, noting that concentrations would be lower with the project, regardless of whether the project adopts portal emissions or ventilation outlet emissions.

The reduction in concentrations in the surrounding community relate to the redistribution of traffic from surface roads to the tunnel, with the distribution of impacts associated with tunnel ventilation not resulting in exposures that are as high as would occur if the project did not proceed at properties located adjacent to surface roads.

In relation to the peak traffic scenarios, there are no 24-hour average concentrations that exceed the NEPC standard or goal.

On the basis of the above assessment, the project would result in lower levels of exposure to $PM_{2.5}$ and PM_{10}, which has the potential for some health benefit to the population in the study area, for both ventilation design options.

5.8.5 Assessment of incremental exposures

Approach

A detailed assessment of potential health effects associated with exposure to changes in air quality as a result of the project has been undertaken. As no threshold has been determined for exposure to $PM_{2.5}$ or PM_{10} the assessment of impacts on health has utilised robust, published, quantitative relationships (exposure-response relationships) that relate a change in $PM_{2.5}$ or PM_{10} concentration with a change in a health indicator. **Annexure A** presents an overview of the methodology adopted for using exposure-response relationships for the assessment of health impacts in a community.

For the assessment of potential exposures to changes in particulate matter, the assessment focused on health effects and exposure-response relationships that are robust and relate to $PM_{2.5}$, being the more important particulate fraction size relevant for emissions from combustion sources. Assessment of PM_{10} has also been included.

The specific health effects (or endpoints) evaluated in this assessment include:

- primary health endpoints:
  - long-term exposure to $PM_{2.5}$ and changes in all-cause mortality (equal or greater than 30 years of age, however the relationship has been applied to all ages)
  - short-term exposure and changes to the rate of hospitalisations with cardiovascular and respiratory disease (equal or greater than 65 years of age).
- secondary health endpoints (to supplement the primary assessment):
  - short-term exposure to $PM_{2.5}$ and changes in cardiovascular and respiratory mortality (all ages)
  - short-term exposure to $PM_{2.5}$ and changes in emergency department admissions for asthma in children aged 1–14 years.

summarises the health endpoints considered in this assessment, the relevant health impact functions (from the referenced published studies) and the associated β coefficient relevant to the calculation of a relative risk (refer to **Annexure A** for details on the calculation of a β coefficient from published studies).

The health impact functions presented in this table are the most current and robust values and are appropriate for the quantification of potential health effects for the health endpoints considered in this assessment.

Table 5-16: Adopted health impact functions and exposure-responses relationships

Health endpoint	Exposure period	Age group	Published relative risk [95 confidence interval] per 10 μg/m^3	Adopted β coefficient (as %) for 1 μg/m^3 increase in PM	Reference
Primary assessment health endpoints					
$PM_{2.5}$: Mortality, all causes	Long-term	≥30yrs, applied to all ages	1.06 [1.04-1.08]	0.0058 (0.58)	Relationship derived for all follow-up time periods to the year 2000 (for approx. 500,000 participants in the US) with adjustment for seven ecologic (neighbourhood level) covariates (Krewski et al. 2009). This study is an extension (additional follow-up and exposure data) of the work undertaken by Pope (2002), is consistent with the findings from California (1999-2002) (Ostro et al. 2006) and is more conservative than the relationships identified in a more recent Australian and New Zealand study (EPHC 2010)
$PM_{2.5}$: Cardiovascular hospital admissions	Short-term	≥65yrs	1.008 [1.0059-1.011]	0.0008 (0.08)	Relationship established for all data and all seasons from US data for 1999 to 2005 for lag 0 (exposure on same-day) (strongest effect identified) (Bell 2012; Bell et al. 2008)
$PM_{2.5}$: Respiratory hospital admissions	Short-term	≥65yrs	1.0041 [1.0009-1.0074]	0.00041 (0.041)	Relationship established for all data and all seasons from US data for 1999 to 2005 for lag 2 (exposure 2 days previous) (strongest effect identified) (Bell 2012; Bell et al. 2008)
Secondary assessment health endpoints					
PM_{10}: Mortality, all causes	Short-term	All ages*	1.006 [1.004-1.008]	0.0006 (0.06)	Based on analysis of data from European studies from 33 cities and includes panel studies of symptomatic children (asthmatics, chronic respiratory conditions) (Anderson et al. 2004)
$PM_{2.5}$: Cardiovascular mortality	Short-term	All ages*	1.0097 [1.0051-1.0143]	0.00097 (0.097)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)
$PM_{2.5}$: Asthma (emergency department admissions)	Short-term	1-14 years	--	0.00148 (0.148)	Relationship established from review conducted on Australian children (Sydney) for the period 1997 to 2001 (Jalaludin et al. 2008)
$PM_{2.5}$: Respiratory mortality (including lung cancer)	Short-term	All ages*	1.0192 [1.0108-1.0278]	0.0019 (0.19)	Relationship established from study of data from 47 US cities for the years 1999 to 2005 (Zanobetti & Schwartz 2009)

* Relationships established for all ages, including young children and the elderly

The assessment of health impacts for a population associated with exposure to particulate matter has been undertaken utilising the methodology presented by the WHO (Ostro 2004) (also outlined in **Annexure A**) where the exposure-response relationships (presented in Table 5-16) have been directly considered.

As discussed in **Section 5.1**, the assessment of health impacts associated with particulate matter has considered population impacts as well as localised impacts.

Population health impacts

Table 5-17 presents the calculated population health risks and incidence (i.e. increase in the number of cases) associated with changes in emissions to air where the design relates to portal emissions or ventilation outlets, as well as emissions from the redistribution of vehicles on key surface roads within the study area (also refer to **Figure 5-5** and **Figure 5-6**) for illustration of the redistribution of impacts for Blackheath and Little Hartley. The table presents the outcomes for the primary health endpoints that relate to $PM_{2.5}$ as these provide the more conservative calculations in terms of risk and incidence. **Annexure E** presents calculations for all health endpoints evaluated.

The change in incidence across the population for each health indicator relevant to changes in nitrogen dioxide exposures in the local community (for the population exposed) has been calculated on the basis of the following:

- the relative risk has been calculated for an annual average incremental change in concentrations (i.e. with project minus without project). The annual average change for all individual receptors modelled has been used as this reflects all residential properties located in the study area, and given the small size of the population adopting the average change is appropriate
- a change in the number of cases associated with the change in nitrogen dioxide impact evaluated in the population within the study area has been calculated (refer to **Annexure C** for details on the methodology). The calculation is undertaken utilising the baseline incidence data relevant for the endpoint considered (refer to **Table 4-4**) and the population present for the study area (assuming the average percentage of age groups for all suburbs in the study area) (refer to **Table 4-2**).

Calculations relevant to the characterisation of risks associated with changes in particulate concentrations in the community are presented in **Annexure E**.

Table 5-17: Calculated population health impacts of changes in $PM_{2.5}$ for the project

Scenario evaluated	Population risk (for primary health end points evaluated)			Change in the number of cases (people in population per year) (for primary health endpoints)		
	Mortality – all causes (all ages)	Hospitalisations Cardiovascular (≥ 65 years)	Hospitalisations Respiratory (≥ 65 years)	Mortality – all causes (all ages)	Hospitalisations Cardiovascular (≥ 65 years)	Hospitalisations Respiratory (≥ 65 years)
Expected traffic scenario						
Portal emissions						
2030	-2×10^{-6}	-4×10^{-6}	-1×10^{-6}	-0.006	-0.002	-0.0006
2040	-2×10^{-6}	-3×10^{-6}	-8×10^{-7}	-0.008	-0.003	-0.0006
Ventilation outlet emissions						
2030	-2×10^{-6}	-4×10^{-6}	-1×10^{-6}	-0.01	-0.003	-0.0008
2040	-2×10^{-6}	-3×10^{-6}	-8×10^{-7}	-0.008	-0.003	-0.0006

The calculated impacts presented in **Table 5-17** indicates that for the population evaluated in the study area, exposures to $PM_{2.5}$ would decrease (decreased population risk and health incidence) with the project, regardless of whether the project adopts portal emissions or ventilation outlet emissions. This is consistent with the predicted reduction in total (background plus project) $PM_{2.5}$ concentrations in the study area (refer to **Table 5-15**). These reductions in $PM_{2.5}$ indicate the project would provide some health benefit to the population.

Localised health impacts

Table 5-18 presents the change in risk associated with the maximum localised change in $PM_{2.5}$ concentrations as a result of emissions to air from portals (where portal emissions are considered) or the ventilation facilities as well as the redistribution of traffic on surface roads.

This redistribution of $PM_{2.5}$ concentrations is illustrated in **Figure 5-5** and **Figure 5-6** that shows the change (or impact) in annual average $PM_{2.5}$ concentrations for Blackheath and Little Hartley, for each ventilation option. These figures illustrate the reduction in $PM_{2.5}$ concentrations adjacent to existing surface roads where traffic volumes are predicted to decrease, with some localised increases adjacent to the ventilation outlet to portals (which includes the locations of impacts assessed in **Table 5-18**).

These calculations relate to the primary health endpoints evaluated in this assessment. These provide the most conservative estimate of localised risk. All calculations, including the secondary health endpoints are included in **Annexure E**.

As discussed in **Section 5.1** the assessment of localised health risks has been undertaken to assist in evaluating the significance of the maximum impacts and inform the need for risk management.

Table 5-18: Calculated maximum individual risk from changes in $PM_{2.5}$ for the project

Scenario evaluated	Maximum individual risk (for primary health end points evaluated)		
	Mortality – all causes (all ages)	Hospitalisations Cardiovascular (≥ 65 years)	Hospitalisations Respiratory (≥ 65 years)
Expected traffic scenario			
Portal emissions			
2030	1×10^{-5}	2×10^{-5}	4×10^{-6}
2040	1×10^{-5}	2×10^{-5}	5×10^{-6}
Ventilation outlet emissions			
2030	1×10^{-6}	2×10^{-6}	6×10^{-7}
2040	2×10^{-6}	2×10^{-6}	6×10^{-7}

All calculated maximum individual risks are less than the risk management action level of 1×10^{-4}, indicating that maximum changes in $PM_{2.5}$ in the local community as a result of the project are considered to be low and acceptable. This outcome is the same irrespective of whether the project adopts portal emissions or emissions from ventilation outlets.

However, it is noted that the calculated maximum individual risks are lower for the design scenario where ventilation outlets are used, compared with the scenario where portal emissions are used.

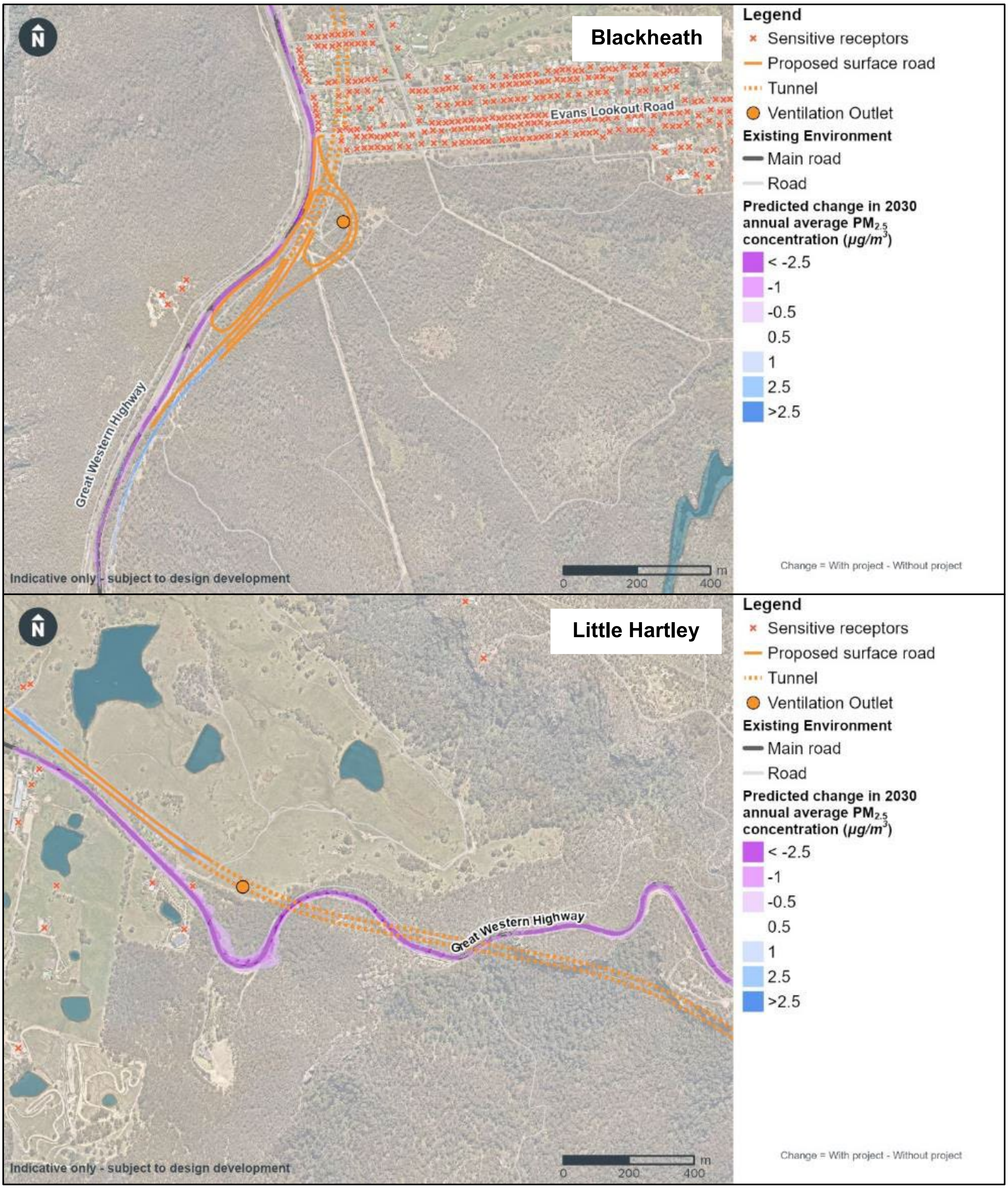


Figure 5-5: Annual average change in $PM_{2.5}$ concentration for ventilation outlet option for 2030 (from Appendix E (Technical report - Air quality) of the EIS)

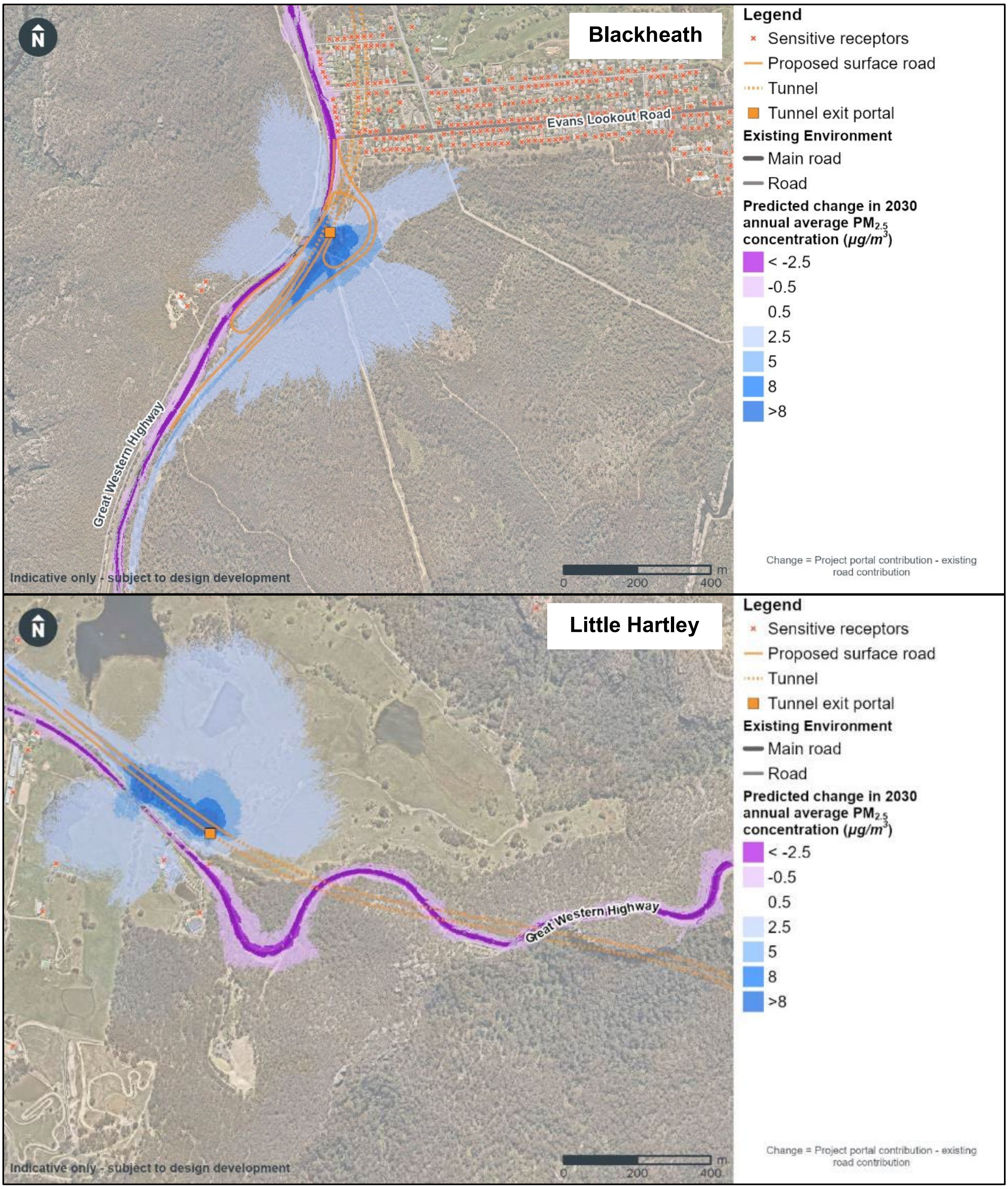


Figure 5-6: Annual average change in $PM_{2.5}$ concentration for portal outlet option for 2030 (from Appendix E (Technical report - Air quality) of the EIS)

Maximum traffic and regulatory worst-case scenarios

The maximum traffic scenario relates to a higher level of traffic in the tunnel during selected times of the year. This scenario reflects likely peak emissions from the project, which may occur only on a few days of the year. The calculated impacts presented in **Table 5-17** and **Table 5-18** are sufficiently low such that any increase in annual average concentrations that may occur as a result of including impacts from the maximum traffic scenario over approximately ten percent of the year does not change the outcomes presented for population and individual risks.

The regulatory worst-case scenario assumes the tunnel is full of vehicles at all times of the day, every day, which is unrealistic. The scenario may reflect a short-duration issue such as an accident or breakdown that may result in the tunnel being significantly congested for a short period of time such as a few hours. As a result, the impacts predicted for this scenario are higher than for the typical traffic and maximum traffic scenarios. Where such an event occurs for a period of 4 hours, once every two weeks of the year, the change in annual average is small, and the increase in the calculated population and individual risks is also small. Overall, there would be no change in the outcomes, in terms of population and individual risk presented above.

The project would result in a decrease in the level of exposure to $PM_{2.5}$ in the population within the study area that may have some long term health benefits. The project, with either portal or ventilation outlet emissions, would result in localised impacts that are considered low and acceptable. However, it is noted that the maximum localised/individual risk is lower where the project design includes ventilation outlets.

5.9 Valuing particulate matter impacts

The Secretary's environmental assessment requirements (as outlined in **Section 1.4**) require the assessment of health impacts to also evaluate costs to the community. More specifically the Secretary's environmental assessment requirements have indicated that costs should be evaluated on the basis of the guideline *Methodology for Valuing the Health Impacts of Changes in Particle Emissions* (EPA 2013).

This guideline has developed an approach for use in Australia that is based on the approach developed in the UK. The approach adopted is simplistic, relating health costs in the community to changes in total tonnes of $PM_{2.5}$ emitted. This calculation has generalised the health impacts associated with changes in $PM_{2.5}$ exposures as emitted to air and does not specifically address how people are exposed to these emissions (this is assumed to occur). The tonnes of $PM_{2.5}$ relevant to each of the scenarios evaluated for this project has been calculated on the basis of the modelling completed and presented Appendix E (Technical report - Air Quality) of the EIS. The calculated tonnes of $PM_{2.5}$ associated with the typical emissions scenario are summarised in **Table 5-19**.

Table 5-19: Estimated total emissions of $PM_{2.5}$ for the project

Scenario	Tonnes of $PM_{2.5}$ per year	
	2030	**2040**
No project – emissions from surface roads only	4.2	9.6
With project (portal emissions or ventilation outlets)		
Emissions from surface roads	1.15	1.10
Emissions from project (east bound and west bound)	1.70	1.96

The above table indicates that, when comparing to the 'without project' scenario there is an overall reduction in emissions to air of $PM_{2.5}$ in 2030 and 2040 for both the portal emissions and ventilation outlet emissions scenarios.

However, the assessment of potential health effects associated with the change in $PM_{2.5}$ concentrations the community are exposed to are different, and as discussed in **Section 5.8.5**, the project is associated with a decrease in incidence, or the number of cases, relevant to mortality and hospitalisations (i.e. a health benefit). These impacts (i.e. the change in number of cases), ideally should be those that are considered in valuing the health impacts.

When applying the NSW EPA (2013) methodology, the study area has been assumed to be "rural" (considered appropriate for the study area), where the damage costs listed are $126,915 per tonne of $PM_{2.5}$ in 2011 prices. In today's (2021) prices, based on the inflation calculator from the Reserve Bank of Australia[8] the damage cost is $152,675 per tonne of $PM_{2.5}$. Following this approach, the damage costs/savings associated with $PM_{2.5}$ are calculated, for both portal emissions and ventilation outlet emissions scenarios, to be:

- around $205,260 (annual saving) in 2030, when comparing the change in total emissions between the 'No project' and the 'With project' scenarios
- around $70,391 (annual saving) in 2040, when comparing the change in total emissions between the 'No project' and the 'With project' scenarios

The above indicates that with the project, regardless of the ventilation scenario adopted, there would be a health benefit (reduction in health costs).

5.10 Summary of outcomes – changes in air quality

The assessment of health impacts associated with changes in air quality associated with the project has concluded the following:

- construction:
    - potential community exposures to dust, where no mitigation measures are implemented pose a low risk to community health. However, dust mitigation is proposed to be implemented, which would result in reductions in dust exposure with risks to community health remaining low
    - odours are not expected to be of significance in the project works
    - these conclusions relate to the construction of the project regardless of whether tunnel ventilation occurs via portals or ventilation outlets.
- operation:
    - potential exposure to volatile organic compounds have been evaluated using health-based guideline, where health impacts are considered negligible
    - potential exposure to benzene, PAHs and DPM are considered to be low and acceptable
    - potential exposures to carbon monoxide are below all relevant health-based guidelines and are considered negligible
    - nitrogen dioxide:

[8] http://www.rba.gov.au/calculator/annualDecimal.html

    - the project would result in a decrease in the level of exposure to nitrogen dioxide in the population within the study area that may have some long term health benefits
    - the project design with either portal or ventilation outlet emissions would result in localised impacts that are considered low and acceptable.
  - particulates:
    - the project would result in a decrease in the level of exposure to $PM_{2.5}$ in the population within the study area that may have some long term health benefits
    - the project, with either portal or ventilation outlet emissions, would result in localised impacts that are considered low and acceptable. However, it is noted that the maximum localised/individual risk is lower where the project design includes ventilation outlets.

Section 6. Assessment of in-tunnel air quality

6.1 General

Exposures that may occur within the tunnels depend on the concentration of pollutants in the tunnels (which would vary depending on the time of day and location within a tunnel, with higher concentrations expected towards the end of each tunnel compared with the entrance) and the time spent in the tunnel.

6.2 In-tunnel air quality limits

The operational in-tunnel limits for the operation of the tunnel under normal conditions are shown in **Table 6-1**.

Table 6-1: In-tunnel air quality limits

Parameter	Units	Limit	Averaging period
Nitrogen dioxide (NO_2)	ppm	0.5	Rolling 15-minute average
	ppm	1.0	Maximum for standing traffic scenario
Carbon monoxide (CO)	ppm	50	Rolling 15-minute average
	ppm	150	Peak
Visibility*	m^{-1}	0.005	Rolling 15-minute average

* Visibility is an important design criteria for in-tunnel safety. Visibility is reduced by the scattering and absorption of light by suspended particulate matter. From a health perspective, exposure to particulate is of relevance. However, such an assessment is limited by the short duration of exposure in tunnels compared with the longer exposure times (24 hours and one year) for which the health effects of ambient particles have been established. Moreover, there is no safe minimum threshold for particles, and so visibility cannot reliably be used as a criterion for health risk (NHMRC 2008). Hence visibility limits within the tunnel have not been further evaluated

The adopted in-tunnel air quality limit of 50 ppm for a 15-minute rolling average and 150 ppm as a peak value is lower than the available health based guidelines for exposure from the WHO (WHO 2010). Therefore, the in-tunnel air quality limits are considered to be adequately protective of the health of tunnel users in relation to carbon monoxide exposures.

Based on current guideline concentrations and car emission technologies, the NO_2 criteria is the hardest to achieve and the pollutant that determines the required air flows and drives the design of ventilation for in-tunnel pollution. Hence the focus of this assessment relates to NO_2 exposures within the tunnel.

The in-tunnel air quality limits are consistent with the NSW Government Advisory Committee on Tunnel Air Quality (ACTAQ) 'In-tunnel air quality (NO_2) policy' (ACTAQ 2016) and the limits applied to other road tunnel projects in Sydney. The tunnel ventilation system, regardless of whether designed for portal emissions or ventilation outlet emissions, has been designed to meet these in-tunnel air quality limits.

Details on the ventilation design that ensures in-tunnel air quality meets the above criteria is presented in the Ventilation Options Report attached to Appendix E (Technical report – Air quality) of the EIS.

6.3 Nitrogen dioxide

Short term exposure to nitrogen dioxide has been shown to cause respiratory health effects and is suspected of causing other health impacts such as cardiovascular effects (USEPA 2016). The concentration at which these impacts occur was subject to a review in 2015 (Jalaludin 2015). This review, which has been used to develop the NSW nitrogen dioxide in tunnel guideline, evaluated available studies in relation to health effects from in-tunnel and short-term exposures to nitrogen dioxide. The review evaluated studies associated with exposures that occur for less than 30 minutes as well as those with exposures of more than 60 minutes.

In relation to the available studies (18 studies) that relate to exposures of 30 minutes or less, the review identified the following (Jalaludin 2015):

- there were no effects identified in relation to lung function for individuals exposed to nitrogen dioxide between 0.12 and 0.5 ppm
- the results for inflammatory markers (physiological measures that indicate the respiratory system or other systems in the body are dealing with inflammation) are mixed
- an effect of exposure to nitrogen dioxide and airway responsiveness was identified in individuals with asthma
- there is no clear evidence of a dose-response relationship for exposure and airway responsiveness for nitrogen dioxide levels at or below 0.5 ppm
- the effects observed for airway responsiveness may be transient. There is no clear evidence that repeated exposure to nitrogen dioxide leads to cumulative effects.

In relation to the available studies (14 studies) that relate to exposures of 60 minutes or more, the review identified the following (Jalaludin 2015):

- there were no effects identified in relation to lung function for individuals exposed to nitrogen dioxide between 0.3 and 4 ppm
- the results for inflammatory markers are mixed, however overall, inflammatory markers increased after exposure to nitrogen dioxide
- an effect of exposure to nitrogen dioxide and airway responsiveness was identified
- insufficient data is available to determine any cardiovascular effects (or otherwise)
- one study indicated the effects were attenuated with repeated exposures.

In relation to the available studies (eight studies) from road tunnels, busy roads and subways, the review identified the following (Jalaludin 2015):

- exposures to nitrogen dioxide were in the range of less than 0.2 ppm (in seven studies) to 0.5 ppm (in one study)
- there were no effects identified in relation to lung function
- both upper and lower respiratory symptoms were commonly reported after exposure to road tunnel and subway environments
- the results for inflammatory markers are mixed
- the effects on airway responsiveness were unclear.

Another review (enRiskS 2018) was undertaken to consider nitrogen dioxide exposures of up to 60 minutes. This review supported the conclusions of the Jalaludin report, even for exposures of nitrogen dioxide up to 60 minutes. It found that for nitrogen dioxide exposures 0.5 ppm or less, the strongest evidence for effects were seen on airways responsiveness, and generally in asthmatics. These effects, if detected were small and not defined to be clinically relevant.

However, there were limitations in the studies, in particular the small number of participants and the lack of subjects who are more sensitive to effects of nitrogen dioxide. Further, when considering the studies conducted in road tunnels, busy roadways and in subways it is important to note that nitrogen dioxide is only part of a complex mixture of air pollution, including $PM_{2.5}$, and determining health effects that may be only related to nitrogen dioxide is difficult.

For the assessment of short duration exposures to nitrogen dioxide in road tunnels, Australia along with a number of other jurisdictions, have established guidelines. The guideline of 0.5 ppm, as a rolling 15-minute average, has been adopted in Australia based on the available studies considered in the reviews presented (enRiskS 2018; Jalaludin 2015), and are considered to be protective of health for users of the tunnels.

In-tunnel concentrations of nitrogen dioxide have been modelled in the Ventilation Options Report attached to Appendix E (Technical report – Air quality) of the EIS for the proposed tunnel design (alignment, gradient, internal volume, length, ventilation design, climate) and ventilation options. These also consider information about the number and mix of vehicles expected in the tunnel, along with emissions data relevant to the vehicle fleet evaluated. The tunnel ventilation has been designed to meet the in-tunnel air quality limits for both portal emissions and ventilation outlet emissions. **Table 6-2** presents a summary of the average nitrogen dioxide concentrations predicted in the tunnel for various trips (noting the travel time in the tunnel would be less than 15-minutes for all speeds considered).

Table 6-2: In-tunnel average nitrogen dioxide concentrations

Scenario	Nitrogen dioxide concentrations (average) (ppm)	
	Eastbound travel (uphill)	Westbound travel (downhill)
Scenarios with capacity traffic*		
20 km/hr @2250 veh/hr and 10%HGV	0.5	0.49
20 km/hr @1125 veh/hr and 17.2%HGV	0.5	0.49
60 km/hr @2600 veh/hr and 9%HGV	0.41	0.18
80 km/hr @2600 veh/hr and 9.2%HGV	0.42	0.14
Normal operations		
2030	0.18	0.06
2040	0.17	0.05
In-tunnel limit	**0.5**	**0.5**

* upper limit average concentration predicted for scenarios operating at capacity traffic based on assessment of adverse pressure conditions, no wind and all jet fans operating. The upper limit average most commonly occurred for adverse pressure conditions.

The nitrogen dioxide concentrations in-tunnel during normal operations in 2030 and 2040 are well below the in-tunnel limit. Where operating at capacity traffic the maximum average concentration equals the in-tunnel air limit but does not exceed the limit.

The concentrations discussed above relate to nitrogen dioxide levels inside the tunnels, not inside the vehicles. A study of NO_2 concentrations inside vehicles travelling in Sydney and using existing road tunnels was commissioned by Transport for NSW in 2016 (PEL 2016) to better understand the relationship between nitrogen dioxide outside the vehicle, and inside the vehicle. The study involved a range of vehicles considered representative of the existing vehicle fleet, travelling through existing tunnels in Sydney and simulating travel times between 45 minutes and 60 minutes over a distance of 30 kilometres.

The concentration of nitrogen dioxide that entered a vehicle depended on the concentration outside the vehicle as well as the air exchange rate relevant to the individual vehicle. The air exchange rate depends on the ventilation, whether on recirculation or not, and a range of factors relevant to the vehicle air tightness, or leakiness.

Within existing tunnels investigated in the study, trip average concentrations of nitrogen dioxide would be generally less than 0.15 ppm. During periods of high traffic volumes and high proportions of heavy vehicles, the trip average concentrations inside the M5 East existing tunnels have been recorded in excess of 0.5 ppm, with levels up to 0.7 ppm. The average concentrations inside the vehicles when ventilation was on recirculation, however, were less than 0.2 ppm. The most recent tunnels in Sydney are designed to ensure that trip average concentrations of nitrogen dioxide do not exceed the 0.5 ppm criterion.

The study found that the use of ventilation on recirculation can significantly reduce concentrations of nitrogen dioxide inside vehicles. The ratio of indoor to outdoor concentrations ranged from 0.06 ppm to 0.32 ppm. This is consistent with the findings from a NSW Health study on vehicles using the M5 East tunnels (NSW Health 2003), where an indoor to outdoor ratio of 0.25 ppm to 0.3 ppm was determined for nitrogen dioxide where ventilation was set to recirculation. When ventilation was not set to recirculation the concentration of nitrogen dioxide was higher inside the vehicles, and in some cases accumulated inside the vehicle after travelling through short tunnels.

Hence when travelling in the tunnel with windows up and ventilation on recirculation, exposure concentrations in the vehicle would be lower than predicted in **Table 6-2.**

On the basis of the available data and information, the potential for adverse health effects for users of the tunnel are considered to be low.

6.4 Particulates

There are no health based guidelines available for the assessment of short-duration exposures to PM within a tunnel. In-tunnel criteria relate to visibility (and safety in using the tunnel). It is expected that the concentration of PM within the tunnel would be higher than ambient air concentrations, and the concentration of PM would increase with increasing distance travelled through the tunnel.

Consideration of visibility criteria in the design of the tunnel ventilation system is required due to the need for visibility levels that exceed the minimum vehicle stopping distance at the design speed. Visibility is reduced by the scattering and absorption of light by PM suspended in the air. The amount of light scattering or absorption is dependent upon:

- particle composition (dark particles, such as soot, are particularly effective at reducing visibility by scattering/reflecting light)
- particle diameter (particles need to be larger than around 0.4 μm to scatter light and reduce visibility)
- particle density.

Particles causing a loss of visibility also have an effect on human health, and so monitoring visibility also provides the potential for an alternative assessment of the air quality and health risk within a tunnel. However, such an assessment is limited by the short duration of exposure in tunnels compared with the longer exposure times (24 hours and 1 year) for which the health effects of ambient exposure to particles have been established. Moreover, there is no safe minimum threshold for particles, and so visibility cannot reliably be used as a criterion for health risk (NHMRC 2008). Visibility limits within the tunnel have thus not been further evaluated in regard to long-term health outcomes.

In relation to potential health effects associated with exposure to particulates within the tunnel the following can be noted:

- the exposure-response relationships for particulate matter that have been established on the basis of adverse health effects from short-term exposures relate to changes in the health effects associated with variability in 24-hour average concentrations of $PM_{2.5}$ in urban air. They do not relate to much shorter variations in $PM_{2.5}$ exposure that may occur within a 24-hour period, where there may be exposures over a few minutes to higher levels of $PM_{2.5}$. No guidelines are currently available for assessing potential health effects that may occur as a result of exposures to particulates that may occur for minutes (or even an hour)
- recent review (WHO 2013a) of available studies in relation to short-duration (less than 24-hour) exposures to particulates indicates the following:
  - epidemiological and clinical studies have demonstrated that sub-daily exposures to elevated levels of particulate matter can lead to adverse physiological changes in the respiratory and cardiovascular system, in particular exacerbation of existing disease. This is generally consistent with the outcome of studies reviewed and considered by the USEPA (USEPA 2009a)
  - the studies available do not cover a range of exposure concentrations, nor do they adequately address other variables such as co-pollutants (gases) or repeated short-duration exposures
  - the studies have not determined if a 1-hour exposure would lead to a different response than a similar dose spread over 24-hours, or if an exposure-response can be determined
  - exposures that occur during the use of various transportation methods (such as in-vehicles) have been found to contribute to and affect 24-hour personal exposures.

No guidelines are thus currently available to evaluate health effects of very short-duration exposures to particulates. However, it is noted that keeping windows closed and switching ventilation to recirculation has been shown to reduce particulate exposures inside the vehicle by up to 80 per cent (NSW Health 2003). Adopting such measures, as is undertaken in other tunnels in NSW, would minimise exposures to motorists within the tunnel.

6.5 Summary of outcomes – in-tunnel air quality

Overall, the proposed in-tunnel air quality limits for carbon monoxide and nitrogen dioxide are considered adequately protective of the health of users of project. In relation to exposures to particulates in the tunnel, there are no guidelines currently available to evaluate health effects of very short-duration exposures to particulates. However, it is noted that keeping windows closed and switching ventilation to recirculation has been shown to reduce particulate exposures inside the vehicle by up to 80 per cent (NSW Health 2003). Adopting such measures would, as a precautionary measure, minimise exposures to motorists within the tunnel.

Section 7. Assessment of noise and vibration impacts on health

7.1 Approach

This section assesses the potential for changes in noise and vibration from the project and how these changes might impact health within the community.

This assessment has drawn on information provided in Appendix G (Technical report – Noise and vibration) of the EIS. All details relevant to the underlying assumptions, methodology and interpretation of impacts relevant to changes in noise and vibration are provided within Appendix G (Technical report – Noise and vibration) of the EIS.

The characterisation of health impacts from changes in noise as a result of the project is complex.

This section presents an overview of the key aspects of the noise and vibration assessment and an assessment of potential health impacts associated with the predicted changes in noise and vibration in the local community. The assessment includes:

- information on the existing noise environment presented in **Section 7.2**
- overview of the noise assessment criteria adopted to determine if these are protective of community health, as presented in **Section 7.3**
- an understanding of the health effects of environmental noise, as presented in **Section 7.4**
- summary of noise and vibration assessments relevant to construction and operations, presented in **Section 7.5**
- assessment of the impact of changes in noise and vibration on community health (exposure and potential impacts), presented in **Section 7.6.**

For the purpose of assessing potential impacts of noise in the surrounding community, 14 noise catchment areas have been identified as shown in **Figure 4-3**. In addition, a number of individual sensitive receptors have been identified as detailed in **Table 4-1**.

7.2 Existing noise environment

The existing noise environment surrounding the project is generally dominated by traffic on the Great Western Highway. The adjacent Blue Mountains railway line is also a key source of noise for receivers in the area.

Around the eastern end of the project in Blackheath, the noise environment is dominated by road traffic noise from the Great Western Highway, with more localised contributions from Brightlands Avenue, Station Street, Prince George Street and Wentworth Street. Land use in this area is predominantly residential and commercial associated with Blackheath. Blackheath also provides a mix of hotels and other short-term accommodation, public spaces and recreational areas. The Blackheath railway station is located in the centre of the village, to the north of land that would be directly affected by the project. The existing noise environment is characteristic of a quiet village setting for receptors located away from the Great Western Highway, with higher existing noise levels experienced by receivers along the highway.

Around the centre of the project, at Soldiers Pinch, the existing noise environment is also dominated by traffic noise from the Great Western Highway. This area is located to the south of Mount Victoria and includes a few isolated receptors. The closest recreational site, Browntown Oval, is several hundred metres to the north and affected by noise from the adjacent highway. Mount Victoria includes a mix residential and commercial receptors, hotels and short term accommodation, and places of worship. As with Blackheath, the existing acoustic environment of Mount Victoria transitions from road noise affected to a quiet village setting with distance from the Great Western Highway and the adjacent railway line.

Around the western end of the project in Little Hartley, there are relatively few receptors with scattered commercial developments along the Great Western Highway and isolated rural residential properties. The relatively flat topography and few intervening structures in this area means that the effects of traffic noise from the existing Great Western Highway are generally experienced at a greater distance from the highway than in Mount Victoria or Blackheath.

Existing noise, as ambient, rating background noise levels and road noise, was also characterised on the basis of ambient noise monitoring conducted at 11 noise locations within the noise catchment areas.

This data indicated that existing noise levels in all three areas are generally higher in the daytime, and in some areas during the evening. Night-time noise levels are relatively low, with rating background noise levels in the range 22 to 40 dB(A). Rating background noise levels during the day and evening varied between 29 and 50 dB(A), and 25 and 42 dB(A) respectively. At locations near existing road noise ambient noise levels varied from 53 to 72 dB(A) during the day and 51 to 69 dB(A) during the night-time period.

7.3 Noise assessment criteria

7.3.1 General

The NSW EPA has prepared a number of guidance documents with regard to the types of noise that are considered in relation to construction and operation of the project. The *NSW Noise Policy for Industry* (NPfI) (NSW EPA 2017), *Construction Noise and Vibration Guideline (for Road and Maritime Work)* (Transport 2022) the *NSW Road Noise Policy* (RNP) (NSW DECCW 2011), and the *Interim Construction Noise Guideline* (ICNG) (NSW DECC 2009) are all relevant to the assessment of noise generated by this project. In all these policies, there is discussion of the need to balance the economic and social benefits of activities that may generate noise with the protection of the community from the adverse effects of noise. The noise assessment criteria adopted relate to levels of noise that can be tolerated or permitted above background before some adverse effect (annoyance, discomfort, sleep disturbance or complaints) occurs.

The *Construction Noise and Vibration Guideline (for Road and Maritime Work)* (Transport 2022) (CNVG) outlines Transport for NSW's approach to assessing and mitigating construction noise. The *Noise Mitigation Guide* (Roads and Maritime Services 2015) (NMG) applies to the assessment and management of noise during operations. These guidelines are considered in addition to the other relevant policy and guidelines from the NSW EPA.

For the assessment of noise and vibration impacts from the project a range of guidelines and criteria have been adopted for the assessment of:

- construction – including surface noise, construction traffic noise, ground-borne noise, vibration, blasting and vibration
- operations – relevant to road noise and fixed facilities.

The following sections provide an overview of the guidelines adopted for each of these aspects. In particular, the basis for the guidelines and relevance to the protection of health and wellbeing is noted.

7.3.2 Construction noise management levels and sleep disturbance criteria

People are usually more tolerant to noise and vibration during the construction phase of projects than during normal operation. This response results from recognition that the construction emissions are of a temporary nature – especially if the most noise-intensive construction impacts occur during the less sensitive daytime period. For these reasons, acceptable noise and vibration levels are normally higher during construction than during operations.

Construction often requires the use of heavy machinery which can generate high noise and vibration levels at nearby buildings and receptors. For some equipment, there is limited opportunity to mitigate the noise and vibration levels in a cost-effective manner and hence the potential impacts should be minimised by using feasible and reasonable management techniques.

At any particular location, the potential impacts can vary greatly depending on factors such as the relative proximity of sensitive receptors, the overall duration of the construction works, the intensity of the noise and vibration levels, the time at which the construction works are carried out, and the character of the noise or vibration emissions.

Appendix G (Technical report – Noise and vibration) of the EIS has considered potential construction noise impacts associated with construction activities for the project, proposed to occur from 2024 to 2031. Potential impacts associated with construction noise and vibration are assessed using typical and worst case works scenarios. Construction noise levels would typically be less that the predicted worst case noise levels. There are some areas within the community where construction impacts from other road projects are proposed, with these works occurring over a longer period of time. Further discussion on issues related to these longer duration impacts, i.e., construction fatigue, are further addressed in the **Section 10**.

The ICNG has been adopted for the assessment of noise during construction works (NSW DECC 2009). These guidelines require that noise impacts from the project be predicted at sensitive receptors. These noise levels are then compared with the project specific assessment thresholds, referred to as noise management levels (NMLs), which are based on an increase above background levels. Where an exceedance occurs, the guidelines require that the proponent must apply all feasible and reasonable work practices to minimise impacts. The NMLs are based on levels of noise above background that may result in reactions (or complaints) by the community. The levels are based on some reaction (noise affected) and a strong reaction (highly noise affected).

In addition to the ICNG, the *Construction Noise and Vibration Guideline* (Transport 2022) provide guidance on the level of noise exceedance above the rating background levels that may be perceived by the community as noticeable, clearly audible, moderately intrusive and highly intrusive.

Levels of noise allowable outside standard work hours, particularly at night, are lower than those permitted during normal work hours. Where construction works are planned to extend over more than two consecutive nights a sleep disturbance assessment is required to be carried out. The following has been considered based on the available information on the levels of noise that result in sleep disturbance:

- a maximum internal noise level below 50 to 55 dB(A) is considered unlikely to cause awakening
- one or two noise events per night, with a maximum internal noise level of 65 to 70 dB(A) are not likely to significantly affect health and wellbeing.

The project has considered that an open window provides up to 10 dB(A) attenuation of noise from outdoors to indoors. Buildings where windows are fixed or cannot otherwise be opened may achieve a great noise level performance. Hence external noise levels of 65 dB(A) are unlikely to result in awakening reactions.

The sleep disturbance criteria have been established for evaluating night-time works (between 10.00 pm and 7.00 am) on the basis of 15 dB(A) above existing noise or the rating background noise levels (L_{A90}), resulting in a screening criteria of 45 dB(A) adopted for most NCAs with the exception of NCA4 where a criteria of 47 dB(A) has been adopted.

The ICNG does not provide direct reference to an appropriate criterion to assess the noise arising from construction traffic on public roads. However, it does refer to the RNP which presents a discussion on assessing feasible and reasonable mitigation measures. In assessing feasible and reasonable mitigation measures, an increase of up to two dB(A) represents a minor impact that is considered barely perceptible to the average person. So, the noise goal applied to traffic movements on public roads generated during the construction phase of the project is an increase in existing road traffic noise levels of no more than two dB(A).

7.3.3 Ground-borne noise criteria

The CNVG provides residential NMLs for ground-borne noise, which are applicable when ground-borne noise levels are higher than the corresponding airborne construction noise levels such as might occur during tunnelling. The CNVG provides ground-borne noise levels at residences for evening and night-time periods only, as the objectives are to protect the amenity and sleep of people when they are at home. The following ground-borne noise levels are applicable for residences:

- evening 40 dB(A) $L_{Aeq\ (15\ minute)}$
- night-time 35 dB(A) $L_{Aeq\ (15\ minute)}$.

These guidelines are applicable during tunnelling and other construction activities.

7.3.4 Vibration criteria

The effects of vibration on human health relates to human comfort. This relates to occupants or users of the building who may be inconvenienced or possibly disturbed. These guidelines are of most relevance to the assessment of community health. Intermittent vibration has been evaluated on the basis of the NSW EPA guideline *Assessing Vibration: A Technical Guideline* (NSW DEC 2006), which is based on vibration dose values (VDV). The criteria for VDV are based on the potential for annoyance (based on the level of vibration over the assessment period). Guidelines for continuous and impulsive vibration are dependent on the time of day they occur and the activity taking place that could be affected.

While not anticipated, should blasting be required, criteria have also been adopted (ANZEC 1990) for the project to minimise impacts on human discomfort and damage to structures, architectural elements and services.

7.3.5 Operational noise criteria

Operational noise impacts have been evaluated on the basis of the RNP, with additional guidance and criteria provided within Transport for NSW's *Road Noise Criteria Guideline* (Transport for NSW 2022b) and NMG. The principles underlying the guidance documents state:

- criteria are based on the road development type a residence is affected by due to the road project
- adjacent and nearby residences should not have significantly different criteria for the same road
- criteria for the surrounding road network are assessed where a road project generates an increase in traffic noise greater than two dB(A) on the surrounding road network
- existing quiet areas are to be protected from excessive changes in amenity due to traffic noise.

The project consists of both new and redeveloped roads or road sections according to the definitions in the guidance documents and so both road types need to be considered in developing project-specific limits.

For residential areas, criteria are established for properties near either freeway/arterial/sub-arterial roads or local roads. In addition, criteria are also available for transition zones, where a graduation between the redeveloped and new road noise criteria applies. These criteria relate to noise levels during the daytime (7.00 am to 10.00 pm) and night-time (10.00 pm to 7.00 am). Night-time noise criteria are aimed at minimising sleep disturbance. Criteria are also available to assessed noise exposures in other types of buildings, including schools, places of worship, open space, childcare, aged care and hospital facilities.

Operational traffic noise from the surrounding road network also required some consideration, with criteria (i.e., an increase by more than two dB(A)) established to determine if such impacts need to be further considered.

Guidelines are also available to evaluate maximum noise levels from roadways, such as those from individual vehicles or trucks (e.g., engine braking).

The assessment has evaluated noise from the operation of fixed facilities, namely the jet-fans within the tunnels, ventilation facilities, substations and water treatment plants. It is expected this would also be carried out during the detailed design phase of the project. Noise from these facilities would need to be assessed on the basis of criteria in the NPfI.

The current approach to assessing potential sleep disturbance is in accordance with the RNP (NSW DECCW 2011). The RNP provides a review of research into sleep disturbance. From the research to date, the RNP concludes that:

- maximum internal noise levels of 50 to 55 dB(A) L_{AFmax} are unlikely to awaken people from sleep
- one or two events per night, with maximum internal noise levels of 65 to 70 dB(A) L_{AFmax}, are not likely to affect health and wellbeing significantly.

It is generally accepted that internal noise levels in a dwelling, with the windows open are 10 dB(A) lower than external noise levels. Based on a worst case minimum attenuation, with windows open, the first conclusion above suggests that short term external noises of 60 dB(A) to 65 dB(A) are unlikely to cause awakening reactions. The second conclusion suggests that one or two noise events per night with maximum external noise levels of 75 dB(A) to 80 dB(A) L_{AFmax} are not likely to affect health and wellbeing significantly.

Guidance is provided in the *Road Noise Mitigation Guideline (Transport for NSW 2022a)* in relation to the evaluation of reasonable and feasible noise mitigation measures. These apply where there are exceedances of the *Road Noise Criteria Guideline* (Transport for NSW 2022b). These guidelines provide triggers for the implementation of noise mitigation measures based on the change in noise, with trigger levels established for increases of 2.0 dB(A), noise impacts that are 5 dB(A) above the noise criteria or there is an increase in noise by 12 dB(A) or more.

In addition, if the noise level contribution from the road proposal is acute (daytime $L_{Aeq(15\ hr)}$ 65 dB(A) or higher, night-time $L_{Aeq(9\ hr)}$ 60 dB(A) or higher) then it qualifies for consideration of noise mitigation even if noise levels are dominated by another road.

7.4 Overview of noise and vibration assessment

7.4.1 Construction noise

Construction noise modelling and assessment has been carried out (as detailed in Appendix G (Technical report – Noise and vibration) of the EIS) in accordance with the applicable NSW guidelines. Noise mitigation has been recommended in accordance with these guidelines, taking into consideration current international practices, health impacts of noise and to protect vulnerable people.

Noise that may be generated during construction has been modelled based on the type of equipment to be used, where the equipment is to be used in relation to the community receptors, the hours of work, the duration of the activities carried out and the local terrain. The assessment is based on the proposed approach to construction of the project and has assessed both typical and worst case works scenarios. In addition, five categories of work that may be required to be carried out, outside of standard construction hours were identified and considered.

A reasonable worst-case assessment has been applied within each NCA in accordance with the CNVG.

The reasonable worst-case scenario is conservative because it assumes all equipment expected to be used at a given site would be operating simultaneously, at a worst case intensity, and with a worst case orientation during a 15-minute period. While the noise levels for the realistic worst case might occur at a sensitive receiver during the works at some point during construction, noise levels associated with the typical scenario would occur more frequently.

In reality, construction noise impacts vary greatly depending on the location of the construction activity within the works area, the distance between noise sources and the nearby receptors, the noise intensity of the activity and the time of day.

However, in both instances, for the reasonable worst case and typical construction scenarios, the noise intensive activities would change and vary over an individual day, evening or night-time period.

Table 7-1 presents a summary of the number of receptors that would experience noise levels in excess of the adopted criteria across all noise catchment areas, for the various stages of works.

In relation to the locations where these exceedances may occur, the following is noted:

- generally, receivers in NCA2 would be the most affected by works around Blackheath and receivers in NCA13 the most affected by works around Little Hartley
- up to 171 receivers would be noise affected at Blackheath during standard construction hours and up to 15 would be highly noise affected. No receivers at Blackheath would be noise affected outside of standard construction hours
- up to five receivers would be noise affected at Mount Victoria during standard construction hours, no receives would be highly noise affected
- no receivers would be affected at Kanimbla
- up to 37 receivers would be noise affected at Little Hartley during standard construction hours and up to two would be highly noise affected. Up to 34 receivers would be noise affected outside of standard construction hours.

Table 7-1: Construction noise impacts – residential receptors

Stage of works	Number of residential buildings across all noise catchment areas where noise criteria are exceeded			
	Standard construction hours	Outside of standard construction hours	Highly noise affected	Sleep disturbance criteria
Site establishment and enabling works	110 20 moderately intrusive 3 highly intrusive	NA	0	NA
Tunnel portal construction	75 2 moderately intrusive 1 highly intrusive	NA	19	NA
Tunnelling and associated works	170 36 moderately intrusive 15 highly intrusive	910 445 clearly audible and highly intrusive – require mitigation 465 require notification of works	15	19 exceed screening level 3 awakening reactions expected Highest impacts associated with excavator activities in NCA12 and NCA13
Surface road upgrade works (noting works would be staged so impacts would be limited at any single point in time)	208 36 moderately intrusive 25 highly intrusive	NA	17	NA
Operational ancillary facilities works (noting works would be staged so impacts would be limited at any single point in time)	69 27 moderately intrusive 6 highly intrusive	NA	7	NA
Finishing works, testing and commissioning (noting works would be staged so impacts would be limited at any single point in time)	60 20 moderately intrusive 5 highly intrusive	NA	5	NA

For the works where the highest number of residential buildings may be impacted, namely tunnelling and associated works **Figure 7-1** to **Figure 7-4** show the predicted noise contours and the noise impacted residential properties identified for Blackheath, Soldiers Pinch and Little Hartley. The distribution of noise impacts is similar (with lower levels of noise) for other works evaluated.

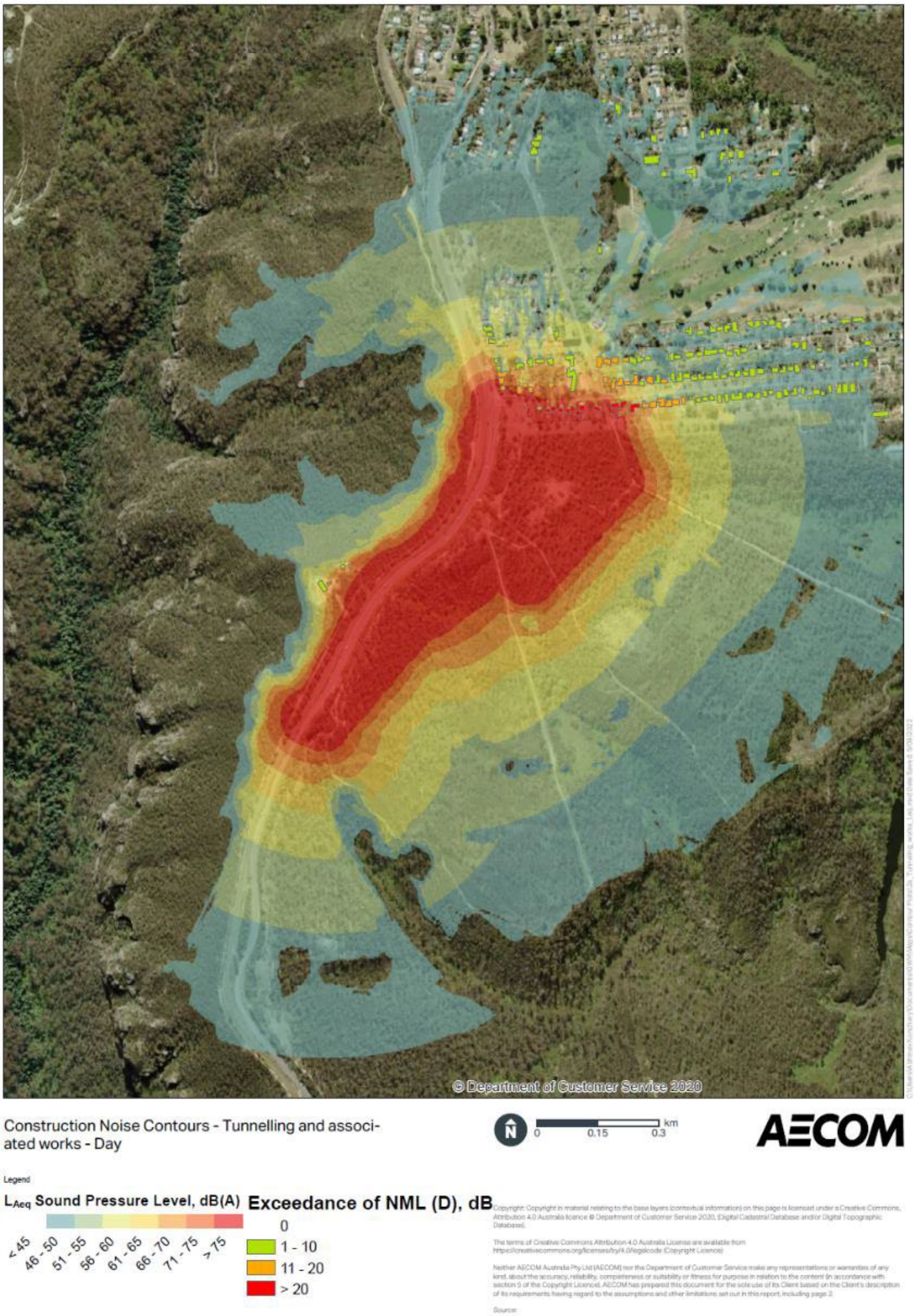


Figure 7-1: Location of construction noise impacts for Blackheath: Tunnelling and associated works – Day (Appendix G (Technical report – Noise and vibration) of the EIS)

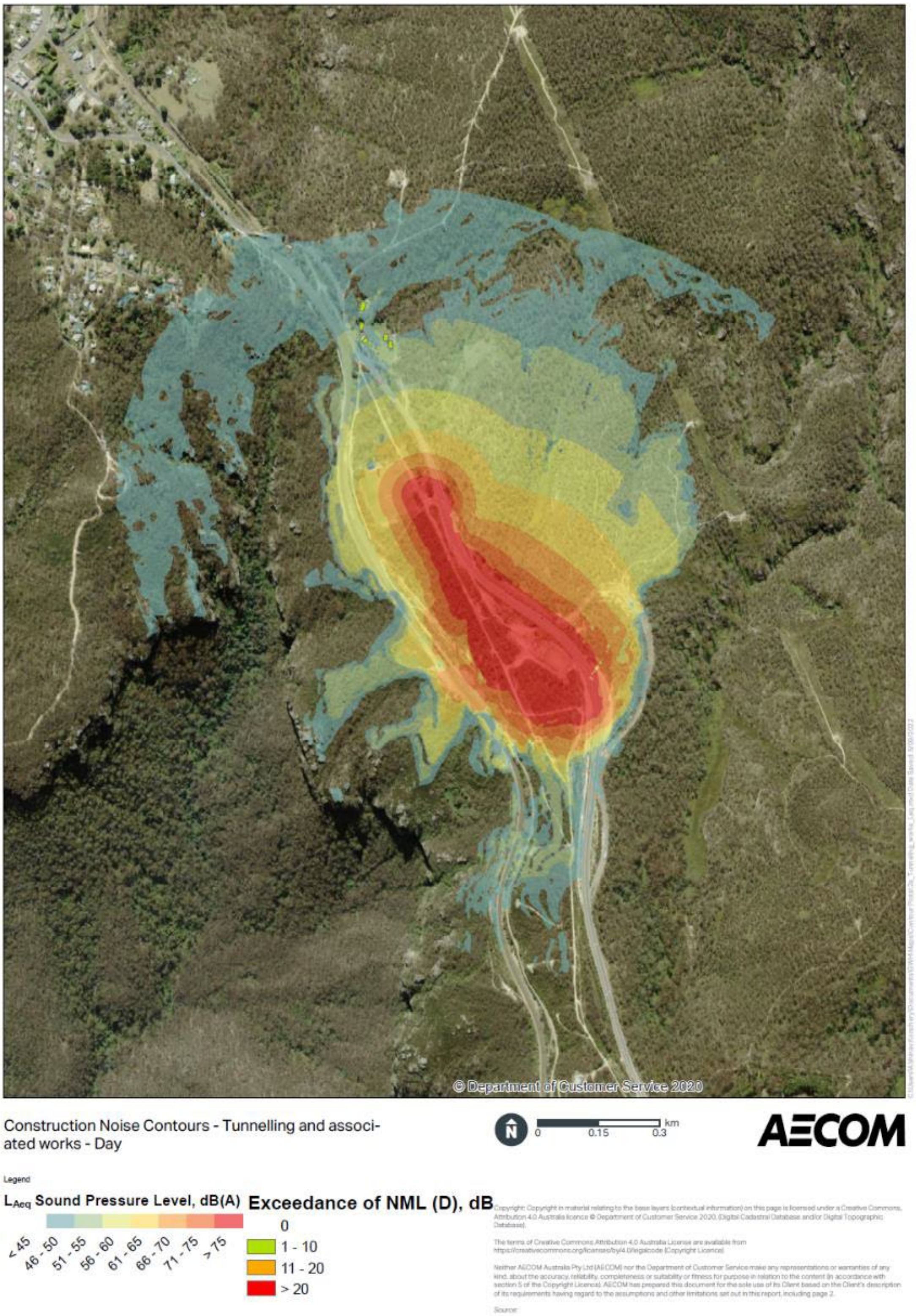


Figure 7-2: Location of construction noise impacts for Soldiers Pinch: Tunnelling and associated works – Day (Appendix G (Technical report – Noise and vibration) of the EIS)

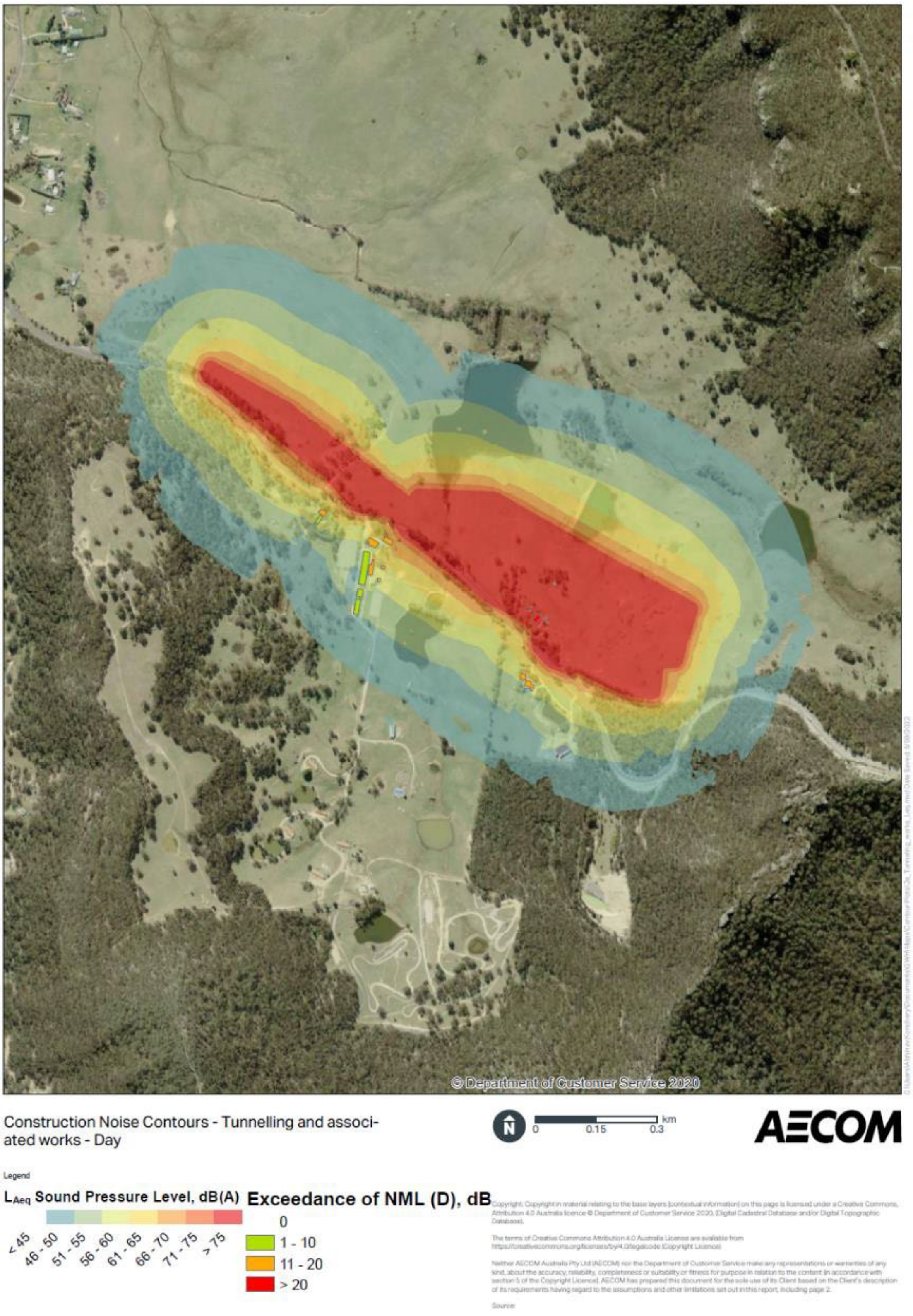
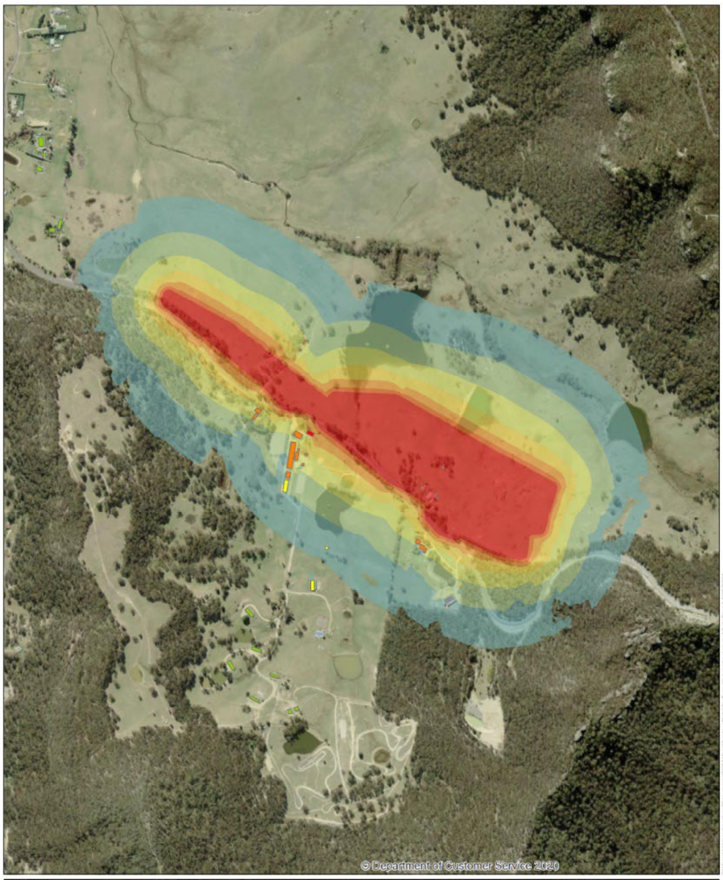
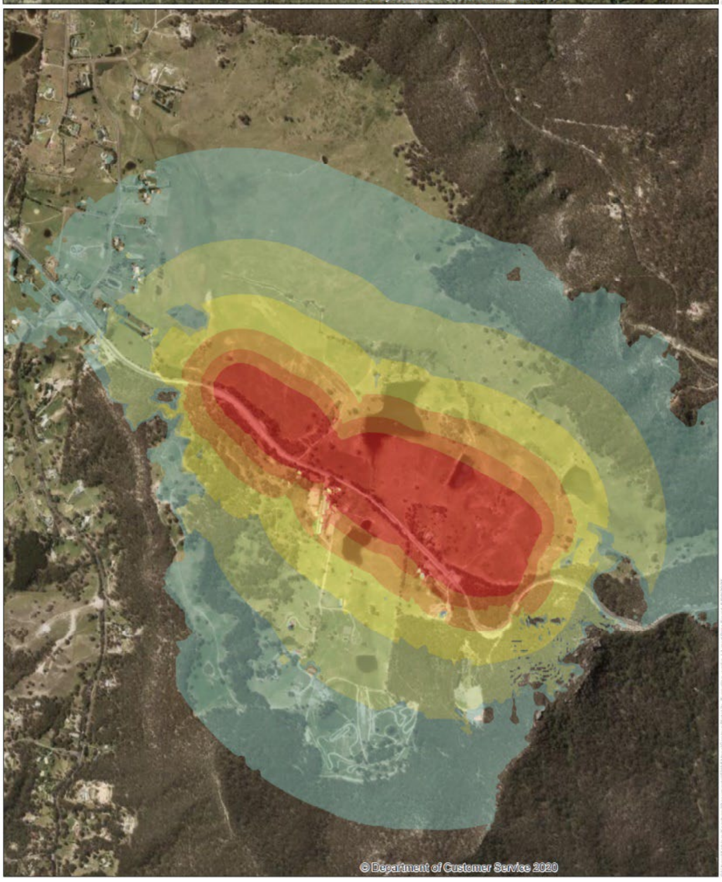


Figure 7-3: Location of construction noise impacts for Little Hartley: Tunnelling and associated works – Day (Appendix G (Technical report – Noise and vibration) of the EIS)



Impacts during the night time period



Sleep disturbance

Figure 7-4: Location of construction noise impacts for Little Hartley: Tunnelling and associated works – Night (Appendix G (Technical report – Noise and vibration) of the EIS)

Construction noise is not predicted to exceed the adopted noise criteria for non-residential receptors.

In relation to construction road traffic noise, daytime traffic movements are predicted to increase noise levels by 0.3 to 1.7 dB(A) during peak construction works (where the maximum number of truck movements would occur) and by 0.1 to 0.7 dB(A) during average construction works. Night-time traffic noise is predicted to increase by 0.6 to 2.6 dB(A) during peak construction works and by 0.2 to 1.0 dB(A) during average construction works.

Increases in road traffic noise of greater than 2 dB(A) (the criteria adopted) have been identified at two sections of the proposed access roads for the night-time peak construction traffic volume scenario. Both these sections are associated with the Little Harley construction site. It is noted that peak construction traffic volumes are a worst-case scenario indicative of peak activities occurring at the same time which is highly unlikely. In the unlikely event that peak construction activities occur at the same time, it is anticipated that it would be for a short duration only. The overall noise impact of construction traffic would be somewhere between the predicted relative increases associated with average construction volumes and peak construction volumes. Additionally, there are minimal receptors at this section of the proposed access roads to be affected by this relative noise increase.

7.4.2 Vibration

A construction vibration assessment has been carried out as detailed in Appendix G (Technical report - Noise and vibration) of the EIS. This identified minimum working distances that would be protective of adverse impacts, with the largest distances based on human comfort criteria. Any works conducted within the distance determined for the protection of human comfort would be notified. Mitigation measures have been identified to manage any works that may be required within the distances protective of cosmetic damage.

7.4.3 Ground-borne noise

The noise that is generated within a room is highly dependent on the soil and rock strata, the distance to the source and the construction of the building. The prediction of ground-borne noise for this project has been based on previous measurements of tunnelling activities from roadheaders and tunnel-boring machines in Sydney, using methods in accordance with ISO14837: *Mechanical vibration - Ground-borne noise and vibration arising from rail systems*, where relevant.

A large number of receptors (127 during the evening and 294 during the night-time period) are predicted to experience ground-borne noise levels which exceed the ground-borne noise criteria. Most of the exceedances are in the range of <10 dB (above the criteria) with some receptors predicted to experience exceedances between 10 and 20 dB above the criteria. The receptors are all located in vicinity of Blackheath (between Evans Lookout Road and Radiance Avenue) with the exception of one receptor near Little Hartley construction site. These exceedances are due to the small slant distance between the tunnel and receptors as these receptors are near the proposed end point of the tunnel just east of Blackheath.

Tunnelling is proposed to progress at a rate of 70 to 90 metres per week. It is likely that ground-borne noise would be discernible for up to five days at each affected receiver with the exceedance occurring for up to two days. Tunnelling advance rates would reduce around the portals, which may increase the duration of exposure for receivers in these areas. As tunnelling moves towards and away from each receiver the noise levels experienced would be increase and decrease respectively.

7.4.4 Management of noise and vibration impacts during construction

During construction a large number of receptors in the community have the potential to experience noise impacts above the adopted criteria, with a substantial proportion of these receptors having the potential to experience noise levels that are considered to be noticeable (up to 10 dB above background noise levels) and highly intrusive (over 30 dB above background noise levels). Hence noise mitigation measures would need to be implemented during construction. Such measures, as standard and additional mitigation measures, would be detailed in a Construction Noise and Vibration Management Plan (CNVMP), as per Appendix G (Technical report - Noise and vibration) of the EIS. The CNVMP details a range of mitigation measures that would result in noise reductions up to 25 dB.

The CNVMP would also include a community consultation and complaints handling process. The consultation measures would include notification of noisy works and more specifically worker where the noise criteria may be exceeded via letterbox drop (or equivalent) and phone calls (for identified/affected residents). Individual briefings would be undertaken where high noise activities may occur with mitigation measures discussed.

Details relating to out of hours works, the works most likely to be of concern to the community and likely to result in increased levels of annoyance and sleep disturbance, would form part of the CNVMP. Noisy works would be scheduled to occur during the day where possible, and if such works are required outside of standard construction hours the works would be as early as possible in the evening period.

Other actions that may be implemented to address noise impacts include respite measures (including alternative accommodation for residents where highly intrusive noise is expected to occur at night) and early installation of architectural treatments.

The CNVMP includes the requirement for monitoring of noise and vibration impacts throughout the construction works.

7.4.5 Operations

Appendix G (Technical report - Noise and vibration) of the EIS provides an assessment of operational noise (specifically road noise and infrastructure noise) for the project in 2030 and 2040. Road traffic noise has been modelled using SoundPLAN v8.2 software which implements the CoRTN algorithm (which has been demonstrated to be suitable for use in Australia). The model utilises a range of inputs including traffic volumes (and composition), speeds, pavement, road alignment, topography and location of buildings. The model underwent a validation process based on existing traffic flows and noise logging data from the study area. The validation step determined the modelling provided a good prediction of noise impacts and no calibration factor was required to be incorporated into the model.

The noise modelling identified both noise reductions and noise increases.

The project has the potential to result in a reduction in noise levels at around 2,000 residential receptors where the tunnel bypasses the existing surface roads.

Noise levels would increase on the upgraded surface road sections of the Great Western Highway where traffic volumes are expected to increase. Noise impacts are predicted to be highest in 2040, where the noise modelling identified the following:

- road traffic noise levels are predicted to exceed the adopted noise criterion at a total of 30 sensitive receptors
- of these 30 noise sensitive receptors:
  - noise levels are predicted to increase by more than 2 dB(A) at one sensitive receiver
  - noise levels are predicted to equal or exceed the cumulative limit at two sensitive receptors (ie ≥ $L_{Aeq(15\ hr)}$ or $L_{Aeq(9\ hr)}$ noise criterion + 5 dB(A))
  - no noise sensitive receptors have been identified as being acute (i.e. ≥ $L_{Aeq(15\ hr)}$ 65 dB(A) or $L_{Aeq(9\ hr)}$ 60 dB(A))
- two sensitive receivers, located in Little Hartley and shown in **Figure 7-5**, are considered to be eligible for the consideration of feasible and reasonable noise mitigation measures, however one of these receptors has already been identified for consideration of noise mitigation measures as part of the Great Western Highway Little Hartley to Lithgow Upgrade (West Section). Noise walls were not considered reasonable given the low number of receptors in this area, hence other methods of noise reduction, including the use of low noise pavement and/or at-property treatment.

Figure 7-5: Location of buildings eligible for treatment in Little Hartley (Appendix G (Technical report – Noise and vibration) of the EIS)

The assessment also considered maximum noise levels, which has the potential to result in sleep disturbance. Maximum noise levels are generally dependent on truck engine braking events, however loud exhausts and horns may also contribute. A truck may engage its engine brakes at any location on the proposal alignment, however the likelihood is dependent on a range of factors, such as road gradient, proximity to junctions, truck condition and individual driver behaviour. Maximum noise events are less likely further away from the alignment, as maximum noise levels decrease at a faster rate with distance than is the case for L_{Aeq} road traffic noise levels. The assessment conducted identified that the study area is already exposed to maximum noise level events that have the potential for awakening reactions (sleep disturbance), with a lower potential for these events to occur as a result of the project due to vehicles using the tunnel and reduced congestion and gradients on surface roads to the west of the western portals and east of the eastern portals.

Where feasible and reasonable, road traffic noise levels from the operation of redeveloped and new roads should be reduced to meet the noise criteria in accordance with Transport procedures. The hierarchy of noise mitigation is firstly to consider at-source noise mitigation measures such as road design and traffic management, then the use of quieter pavements. If these measures cannot be designed to meet the noise criteria the use of 'in corridor' mitigation measures should be considered, which are generally noise barriers and mounds. Finally, if the applicable noise criteria cannot be met by using a combination of all these methods, at-receiver mitigation measures can be considered such as architectural treatments and property boundary walls.

In relation to fixed facilities (ventilation equipment, transformers, and emergency pumps) the noise modelling identified the following:

- portal ventilation option
    - noise levels are predicted to exceed the L_{Aeq} controlling noise criterion for normal traffic conditions at one receptor at Blackheath (exceedances up to 1 dB). No exceedances are predicted at Little Hartley
    - noise levels are predicted to exceed the L_{Aeq} controlling noise criterion for low flow traffic conditions at one receptor at Blackheath (exceedances up to 1 dB). No exceedances are predicted at Little Hartley
    - noise levels are predicted to exceed the L_{Aeq} controlling noise criterion for emergency conditions at 14 receptors at Blackheath (exceedances up to 4 dB). No exceedances are predicted at Little Hartley.
- ventilation outlet option
    - noise levels are predicted to exceed the L_{Aeq} controlling noise criterion for normal traffic conditions at three receptors at Blackheath (exceedances up to 1 dB) and two receptors at Little Hartley (exceedances up to 2 dB)
    - noise levels are predicted to exceed the L_{Aeq} controlling noise criterion for low flow traffic conditions at four receptors at Blackheath (exceedances up to 2 dB) and four receptors at Little Hartley (exceedances up to 4 dB)
    - noise levels are predicted to exceed the L_{Aeq} controlling noise criterion for emergency conditions at 19 receptors at Blackheath (exceedances up to 5 dB) and four receptors at Little Hartley (exceedances up to 4 dB).

It is noted that exceedances in the ventilation outlet option are due mainly to jet fans located near the exits of each portal (utilised to force exhaust gases against the flow of traffic). To reduce noise emanating from the tunnel portals for these scenarios, quieter jet fans could be selected, or the use of attenuators could be investigated for the jet fans adjacent to the portal exit.

Most exceedances occur under emergency conditions where traffic flow would reduce to 20 km/hr, completely stop, and/or a fire would be present in the tunnel. The exceedances at Blackheath influenced by the operation of the fire pump.

For the portal ventilation option, the number of receptors impacted would be lower and the level of exceedance of the noise criteria is lower.

7.5 Health effects of noise

7.5.1 General

The assessment of noise impacts summarised in **Section 7.4** evaluated noise impacts against regulatory noise criteria relevant to the project. Not all these criteria specifically link to the protection of health and so a further, more detailed assessment of noise impacts on health has been undertaken. The further assessment of noise impacts in the community has focused on the impacts of changes in the noise environment on the health of the community.

Environmental noise has been identified (I-INCE 2011; WHO 2011, 2018) as a growing concern in urban areas because it has negative effects on quality of life and wellbeing and has the potential for causing harmful physiological health effects. With increasingly urbanised societies, impacts of noise on communities have the potential to increase over time.

Deciding on the most effective noise management options in a specific situation is not just a matter of defining noise control actions to achieve the lowest noise levels or meeting arbitrarily chosen criteria for exposure to noise. The goal should be designed to achieve the best available compromise between the benefits to society of reduced exposure to community noise versus the costs and technical feasibility of achieving the desired exposure levels given the project. On the one hand, there are the rights of the community to enjoy an acceptably quiet and healthy environment. On the other hand, there are the needs of the society for new or upgraded facilities, industries, roads, and recreation opportunities, all of which typically produce more community noise (I-INCE 2011; WHO 2011, 2018).

Sound is a natural phenomenon that only becomes noise when it has some undesirable effect on people or animals. Unlike chemical pollution, noise energy does not accumulate either in the body or in the environment, but it can have both short-term and long-term adverse effects on people. These health effects include (WHO 1999, 2011, 2018):

- sleep disturbance (sleep fragmentation that can affect psychomotor performance, memory consolidation, creativity, risk-taking behaviour and risk of accidents)
- annoyance
- cardiovascular health
- hearing impairment and tinnitus
- cognitive impairment (effects on reading and oral comprehension, short and long-term memory deficits, attention deficit).

Other effects for which evidence of health impacts exists, and are considered to be important, but for which the evidence is weaker (and has not been further assessed in this report), include:

- effects on quality of life, well-being and mental health (usually in the form of exacerbation of existing issues for vulnerable populations rather than direct effects)
- adverse birth outcomes (pre-term delivery, low birth weight and congenital abnormalities)

- metabolic outcomes (type 2 diabetes and obesity).

Within a community, the severity of the health effects of exposure to noise and the number of people who may be affected are schematically illustrated in **Figure 7-6.**

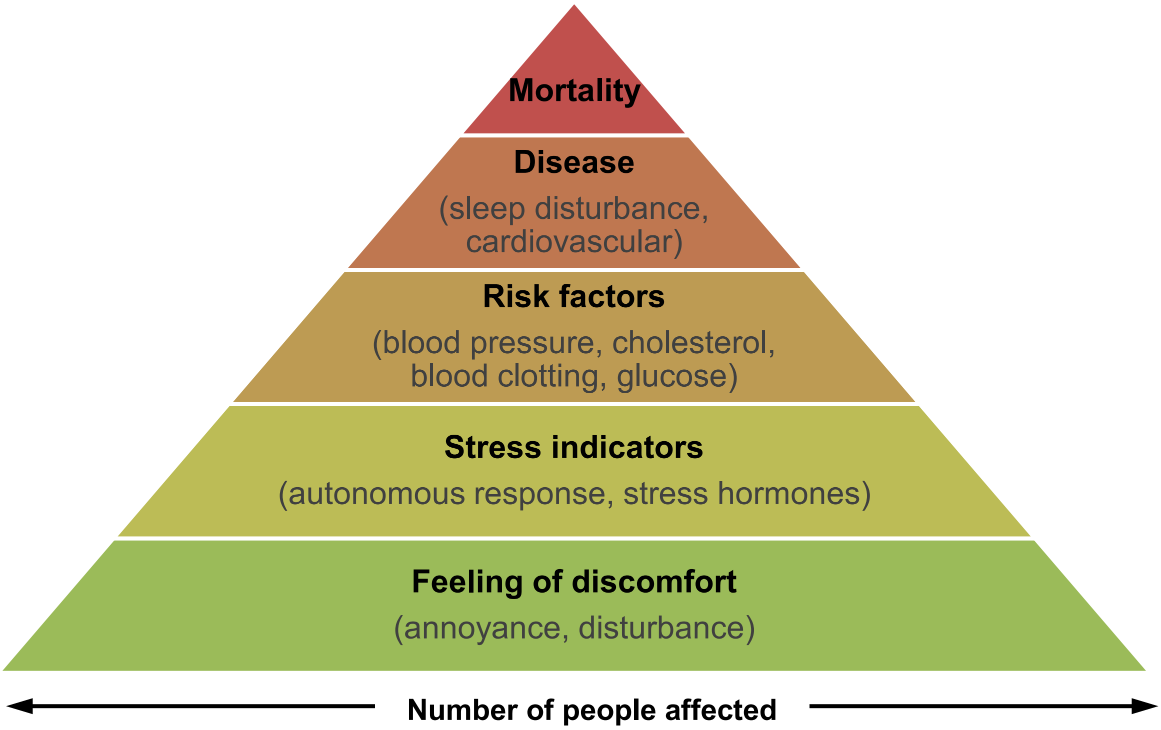


Figure 7-6 Schematic of severity of health effects of exposure to noise and the number of people affected (WHO 2011)

Often, annoyance is the major consideration because it reflects the community's dislike of noise and their concerns about the full range of potential negative effects, and it affects the greatest number of people in the population (I-INCE 2011; WHO 2011, 2018).

There are many possible reasons for noise annoyance in different situations. Noise can interfere with speech communication or other desired activities. Noise can contribute to sleep disturbance which has the potential to lead to other long-term health effects. Sometimes noise is just perceived as being inappropriate in a particular setting without there being any objectively measurable effect at all. In this respect, the context in which sound becomes noise can be more important than the sound level itself (I-INCE 2011; WHO 2011, 2018).

Different individuals have different sensitivities to types of noise, and this reflects differences in expectations and attitudes more than it reflects any differences in underlying auditory physiology. A noise level that is perceived as reasonable by one person in one context (e.g., in their kitchen when preparing a meal) may be considered completely unacceptable by that same person in another context (e.g., in their bedroom when they are trying to sleep). In this case the annoyance relates, in part, to the intrusion from the noise. Similarly, a noise level considered to be completely unacceptable by one person, may be of little consequence to another even if they are in the same room. In this case, the annoyance depends almost entirely on the personal preferences, lifestyles and attitudes of the listeners concerned (I-INCE 2011; WHO 2011, 2018).

Perceptible vibration (e.g., from construction activities) also has the potential to cause annoyance or sleep disturbance and so adverse health outcomes in the same way as airborne noise. However, the health evidence available relates to occupational exposures or the use of vibration in medical treatments. No data is available to evaluate health effects associated with community exposures to perceptible vibrations (I-INCE 2011; WHO 2011, 2018).

It is against this background that an assessment of potential noise impacts of the project on health was undertaken.

7.5.2 Health effects of road traffic noise

Road traffic noise is caused by the combination of rolling noise (noise from tyres on the roadway) and propulsion noise (from engine, exhaust and transmission).

A number of large international studies are available that have specifically evaluated health impacts associated with exposure to road traffic noise. Where exposure to road traffic noise is associated with, or can be shown to be causal, adverse health effects an exposure-response relationship is often established. The main health effects that have been studied in these types of investigations in relation to road traffic noise are annoyance, sleep disturbance, cardiovascular disease, stroke and memory/concentration (cognitive) effects. The most recent review of noise and impacts on health, presented by the WHO (WHO 2018) included a detailed review of the available literature, including impacts specifically related to road noise.

Cardiovascular effects

Cardiovascular diseases are the class of diseases that involve the heart or blood vessels, both arteries and veins. These diseases can be separated by end target organ and health outcomes. Strokes reflecting cerebrovascular events and ischaemic heart disease (IHD) or coronary heart disease (CHD) are the most common representation of cardiovascular disease.

High-quality epidemiological evidence on cardiovascular and metabolic effects of environmental noise indicates that exposure to road traffic noise increases the risk of IHD.

A link between noise and hypertension is relatively well established in the relevant literature. Whilst there is not a consensus on the precise causal link between the two, there are a number of credible hypotheses. A leading hypothesis is that exposure to noise could lead to triggering of the nervous system (autonomic) and endocrine system which may lead to increases in blood pressure, changes in heart rate, and the release of stress hormones. Depending on the level of exposure to excess noise, the duration of the exposure and certain attributes of the person exposed, this can cause an imbalance in the person’s normal state (including blood pressure and heart rate), which may make a person hypertensive (consistently increased blood pressure) which can then lead to other cardiovascular diseases (DEFRA 2014). This hypothesis is illustrated in **Figure 7-7**.

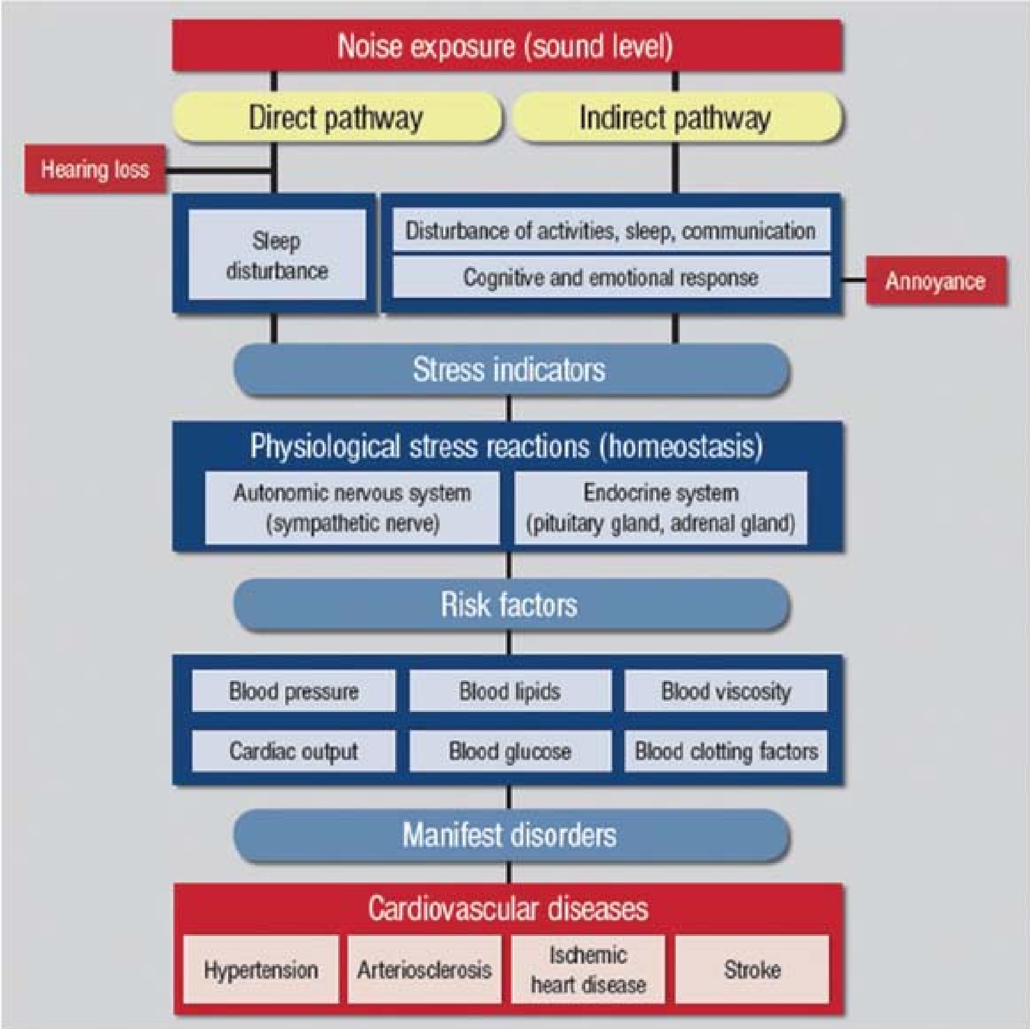


Figure 7-7: Noise reaction model/hypothesis (Babisch 2014)

The available studies regarding road traffic noise and cardiovascular disease risk largely involve meta-analysis (i.e., statistical analysis that combines the results of multiple scientific studies). A number of studies have been published by Babisch (Babisch 2002, 2006, 2008, 2014; van Kempen & Babisch 2012) and others (WHO 2018) have provided the basis for a number of exposure-response relationships adopted for the assessment of cardiovascular health effects associated with road-traffic noise.

In relation to hypertension the most relevant recent study (van Kempen & Babisch 2012) involved analysis of 27 studies between 1970 and 2010, where a relationship between road traffic noise and hypertension was determined. This relates to the incidence of hypertension in the population and has been adopted by the European Commission for the assessment of health impacts of road noise in Europe (EEA 2014). Review by the WHO (2018) considered that the available studies on the incidence of hypertension and road noise provided evidence that was rated very low quality. The relationship recommended by the WHO relates to a non-statistically significant outcome in relation to hypertension. On this basis the relationship as adopted by the European Commission (EEA 2014) has been used in this assessment.

For the assessment of IHD, the WHO (WHO 2018) has undertaken a meta-analysis of three cohort studies and four case-control studies that investigated a relationship between road noise and the incidence of IHD. The meta-analysis involved 67 224 participants (from 7033 cases). The relationship established by the WHO, which is specific to road noise, has been adopted in this assessment. The relationship established was considered to be based on high quality evidence.

Review of the incidence of stroke and road noise by the WHO (2018) determined that the available cohort studies and cross-sectional studies showed mixed outcomes, with the evidence rated very low to moderate quality. In relation to the risk of stroke from exposure to noise, there are limited meta-analysis type studies available and the studies available combine the risks from noise from road and air transport. A more specific study that just investigated the link between road traffic noise and cardiovascular disease/mortality has been undertaken in London (Halonen et al. 2015). This was a large epidemiological study that identified statistically significant associations between road traffic noise (as modelled to residential dwellings) and hospital admissions for stroke and all-cause mortality.

The relationships determined in the above studies relate to noise exposures in excess of a threshold. The threshold for where these effects are of significance are generally equal to or above the noise criteria adopted for the assessment of operational noise impacts. It is noted, however that in areas already affected by noise at levels above these thresholds, the guidelines relate to an increase in noise attributed to the project, with a guideline of two dB(A) adopted. Where an increase in noise by two dB occurred in a noise environment above the threshold for effects, this change in noise would not be associated with unacceptable cardiovascular risks (where the above exposure-response relationships were considered). In areas where existing or predicted total noise levels (as L_{den}) are 55 dB(A) and higher, an increase of five dB(A) would result in an increase in mortality risks (all causes, all ages) that would be considered unacceptable.

<u>Annoyance and sleep disturbance</u>

Changes in annoyance and sleep disturbance associated with noise are considered to be pathways for the key health indicators listed above. However, these issues are of importance to the local community and so it is relevant to evaluate the changes in levels of annoyance and sleep disturbance as a result of noise from the operation of the project within the community.

<u>Annoyance</u>

Annoyance is a feeling of displeasure associated with any agent or condition known or believed by an individual or group to adversely affect them. Annoyance following exposure to prolonged high levels of environmental noise may also result in a variety of other negative emotions, for example feelings of anger, depression, helplessness, anxiety and exhaustion (EEA 2014).

Annoyance levels can be reliably measured by means of an International Organisation for Standardization/Technical Standard (ISO/TS) 15666:2003 defined questionnaire, which has enabled the identification of relationships between annoyance and noise sources. The European Commission (EC 2002) conducted a review of the available data and provided recommendations on relationships that define the percentage of persons annoyed (%A) and the percentage of persons highly annoyed (%HA) to total levels of noise reported as L_{DEN} (i.e. average noise levels during the day, evening and night). These relationships have also been reviewed by the WHO (WHO 2018), where the key outcome of %HA was considered most appropriate for determining actions and outcomes in relation to road noise. Hence this assessment has focused on %HA.

It is noted that the published studies that evaluate noise annoyance and define the %HA have been conducted at different times, using different questionnaires and hence the relationships determined from these studies tend to vary. This makes quantification of noise annoyance impacts challenging.

The available noise guidelines have been developed to address noise annoyance within the community. At most receptor locations the change in noise exposure as a result of the project is a reduction. However, where noise levels are predicted to increase by two dB(A), this has the potential to result in a small increase in individuals highly annoyed by noise. The increase in noise annoyance is not considered to be significant.

Where an increase in noise of five dB(A) is considered (consistent with the increase in noise identified in the discussion above that may be associate with unacceptable increases in mortality), this would result in an increase in the number of individuals that may be considered highly annoyed by noise. While noting the challenges in quantifying the %HA by noise, where the noise-response relationship developed from a systematic review of studies specific to road noise (Guski, Schreckenberg & Schuemer 2017) is adopted for environments where noise levels are in the range 45 and 75 dB(A) (as L_{den})[9], increases in noise less than five dB(A) would not be considered to result in a significant increase in the %HA.

<u>Sleep disturbance</u>

It is relatively well established that night time noise exposure can have an impact on sleep (WHO 2009, 2011). Noise can cause difficulty in falling asleep, awakening and alterations to the depth of sleep, especially a reduction in the proportion of healthy rapid eye movement sleep. Other primary physiological effects induced by noise during sleep can include increased blood pressure, increased heart rate, vasoconstriction, changes in respiration and increased body movements (WHO 2011). Exposure to night-time noise also may induce secondary effects, or so-called aftereffects. These are effects that can be measured the day following exposure, while the individual is awake, and include increased fatigue, depression and reduced performance.

Studies are available that have evaluated awakening by noise, increased mortality (i.e. increase in body movements during sleep), self-reported chronic sleep disturbances and medication use (EC 2004). The most easily measurable outcome indicator is self-reported sleep disturbance, where there are a number of epidemiological studies available. From these studies the WHO (WHO 2009, 2011, 2018) identified an exposure response relationship that relates to the percentage of persons sleep disturbed (%SD) and highly sleep disturbed (%HSD) to total levels of noise reported as L_{night} (i.e. average noise levels during night, which is an 8-hour time period, as measured outdoors). The relationship adopted relates to the assessment of road-traffic noise, with other relationships for air and rail traffic noise. These relationships have been adopted by the WHO (2009, 2011), UK and European Environment Agency (DEFRA 2014; EEA 2010, 2014). Review by the WHO (WHO 2018), considered that the key outcome of %HSD was considered most appropriate for determining actions and outcomes in relation to road noise. Hence this assessment has focused on %HSD.

[9] The relationship adopted from Guski et al (2017) is relevant to flatter landscapes (i.e., with alpine and Asian studies excluded, which include significant terrain features)

For night-time noise levels between 45 and 65 dB(A), increases in noise levels at night time of five, 10, 15 and 20 dB(A) may result in an approximate three, seven, 12 and 18 per cent increase respectively in individuals who are highly sleep disturbed.

The available noise guidelines include criteria to address sleep disturbance that are based on the above studies and relationships. Hence compliance with these guidelines would address health impacts associated with sleep disturbance in the community.

Cognitive effects

There is evidence for effects of noise on cognitive performance in children such as lower reading performance (WHO 2011). A major study was carried out in the EU – RANCH – and this study was reviewed in WHO (2011).

The study found an exposure response relationship between noise and cognitive performance in children for aircraft noise but the relationship between performance and noise for road traffic was much less clear (Stansfeld et al. 2005a; Stansfeld et al. 2005b; WHO 2011, 2018). WHO (2011) used the aircraft noise relationships to assess the impact of noise on children's cognitive performance. For this project, it was not considered appropriate to use the relationships based on the impacts of aircraft noise. The same study showed that road traffic alone did not show an association between road traffic noise and adverse changes in children's cognitive functions studied (reading comprehension, episodic memory, working memory, prospective memory or sustained attention), nor with sustained attention, self-reported health, or mental health.

7.5.3 Individual road noise events

It is noted that noise impacts can also occur because of individual noise events, such as engine braking or loud exhausts. The noise measures adopted above for the assessment of the health effects of noise relate to an average/equivalent sound level over different time periods, which, when measured, would include individual noise events. This is the preferred approach for evaluating annoyance and other health effects related to noise (NSW DECCW 2011). Individual noise events are of most significance in relation to the assessment of sleep disturbance. The available research indicates that one or two individual noise events per night, with a maximum indoor noise level of 65-70 dB(A) are not likely to affect health and wellbeing (NSW DECCW 2011). Criteria have been adopted to address maximum noise events; however, it is noted that it is not possible to model all individual noise events as these relate to individual vehicles or trucks and individual driving behaviour that cannot be predicted.

7.6 Assessment of noise related health impacts from project

7.6.1 Noise criteria

In relation to this project, potential noise impacts have been assessed against Australian (more specifically NSW) criteria that have been established on the basis of the relationship between noise and health impacts. The criteria developed for use in the assessment for control of noise come from policy documents developed by the NSW Government including the NPfI, the ICNG and RNP. All of these policies are based on the health effects of noise outlined in the reviews published by the following organisations:

- World Health Organization – *Environmental Noise Guidelines for the European Region* (WHO 2018)

- World Health Organization – *Guidelines on Community Noise – Health effects of noise* (WHO 1999)
- World Health Organization – *Night Noise Guidelines for Europe* (WHO 2009)
- International Institute of Noise Control Engineering – *Guidelines for Community Noise Impact Assessment and Mitigation* (I-INCE 2011)
- Environmental Health Council of Australia – *The health effects of environmental noise – other than hearing loss* (enHealth 2004).

Various attempts have been made to assess the effect (measured by average reported annoyance, sleep disturbance or a similar type of effect) from community noise (measured by long term average sound levels) to develop exposure-response relationships. As individual reactions to noise are so varied, these studies need large sample sizes to obtain reasonable correlation between the noise exposure and the response. Any dose-response relationship determined from large studies over a range of communities and cultures will not necessarily represent the reaction of individuals or small communities. These exposure-response relationships are of value for macro-scale (i.e., whole urban environment scale) strategic assessment purposes where individual differences are not important; however, they are not as useful when considering potential impacts on a small population located close to a specific project/activity.

For a number of the noise guidelines (including the RNP), the criteria have been established on the basis of noise annoyance, which is considered to be the more sensitive effect and an effect that is assumed to precede the physiological effects. As a result, these guidelines are designed to be protective of all adverse health effects. Other guidelines are based on specific sensitive health effects such as sleep disturbance for the assessment of night-time noise.

As guidelines/criteria that are based on the protection of health are available to assess construction and operational noise impacts associated with this project, the assessment of potential health impacts has focused on whether the guidelines/criteria established can be met. Where the guidelines cannot be met then there is the potential for the above adverse health effects to occur in the community adjacent to the project.

In most cases, when developing management limits for the project, it has been assumed that there is a 10 dB(A) difference between noise inside and outside of a building with windows open. This assumption is sourced from the RNP. Further consideration of this assumption raises a number of issues including:

- internal noise levels are defined in the RNP as those measured in the centre of a habitable room so if activities (like sleeping or concentrating) happen at the edge of a room they may be more impacted by noise than might be expected
- the RNP refers to windows being open sufficient to provide adequate ventilation as discussed in the Building Code of Australia. The Building Code of Australia does not require that residential buildings have significant levels of ventilation and, as a result, opening a window sufficient to provide the minimum ventilation required is unlikely to mean that the window is completely open or even that more than one window in a room is opened. Sufficient ventilation may result from the existing drafts in a building (with no windows open) or the opening of two windows only for the entire building. Assuming that the 10 dB(A) change in noise applies for all situations where windows are open is not appropriate

- consequently, the use of this assumption in setting noise management limits for this project may need to be reviewed when designing property specific noise mitigation measures (to be carried out in consultation with the property owner).

7.6.2 Construction noise

A significant number of residential receptor buildings are predicted to experience noise levels above the relevant noise management levels (refer to **Table 7-1**). The assessment undertaken is based on the worst-case 15-minute period of construction activity, where construction equipment is closest to the sensitive receptors. The assessment does not represent long-term or chronic noise impacts at the receptors identified.

Particularly noisy activities, such as rock hammering and use of concrete saws, are likely to persist for only a fraction of the overall construction period. In addition, the predictions use the shortest separation distance to each sensitive receiver, however in reality separation distances would vary between plant and sensitive receivers. For linear works (works that move along the road alignment, rather than works located at a construction site) noise exposure at each receiver would reduce due to increases in distance loss as the works progress along the alignment. Typical noise levels could be 5 to 10 dB(A) lower than predicted depending on the site and nature of works.

The most noise intensive activities would be schedule during standard day time construction hours wherever practicable. There are, however, noise intensive activities that would be required outside standard construction hours at certain locations for a variety of reasons, typically to avoid substantial disruption on the existing road network.

During standard construction hours noise impacts are predicted to exceed the noise management levels by >20 dB(A) in noise catchment areas NCA 2, 3, 12 and 13.

Long-term (i.e., over a year or more) noise increases of greater than five dB(A) have been associated with unacceptable mortality risks, along with an unacceptable increase in highly annoyed receptors. As noted above, the construction noise impacts predicted are peak or worst-case noise levels associated with specific construction activities many of which occur for very short periods of time only. The peak noise levels predicted are unlikely to be reflective of long-term noise levels in the community hence the potential for health impacts would be lower than indicated by the noise exceedances predicted during the daytime.

Maximum night-time noise levels would be generated during tunnelling and associated works. In some instances, maximum noise levels at night are predicted to exceed noise management by more than 25 dB(A) at three receptors in Little Hartley (NCA12 and NCA13) with exceedance the sleep disturbance screening level expected at up to 19 receptors (refer to **Section 7.3.2**). Maximum noise levels at night are also predicted to exceed the awakening reaction levels at three receptors. These impacts relate to works occurring during tunnelling and associated works at Little Hartley. It is expected that the detailed design would include notification of night-time works, and consideration of hoarding and noise barriers around these sites to mitigate the noise impacts identified.

At night-time, increases in noise levels of 20 dB(A) or more are associated with an additional 18 per cent of the population experiencing highly disturbed sleep. Hence the short-term noise impacts associated with construction activities at night, where unmitigated, would be expected to result in a significant increase in sleep disturbance for residents located close to the Little Hartley construction footprint. As noted above the night-time noise impacts would be expected to be mitigated through the incorporation of hoarding and/or noise barriers at construction sites. It is important that such noise reduction features are designed to minimise night-time noise impacts on the community.

In reality, exceedances of the noise management level and the number of impacted residential receptor buildings would vary over the duration of construction given:

- construction noise levels are assessed at the most affected façade of a receptor building, and noise levels presented in the assessment reflect the noise level for the receptor building with the highest predicted noise level in each NCA. Actual noise levels would usually be less than those presented in the assessment where receptors are further away from the construction works or have increased shielding (i.e., from other buildings)
- in practice, not all plant would typically operate all the time and actual noise levels would be lower than predicted. Further, particularly highly noisy activities (e.g., piling) would be intermittent, typically occur during standard working hours and would likely be subject to respite periods
- the assessment results present the highest noise level that could result over the entire stage and does not show an individual 15-minute period. In reality, noise intensive activities would change and vary over an individual day, evening or night-time period
- the predicted noise levels are only likely to occur when works are at the closest point to each receptor building. However, for many work areas, construction activities move around and so construction noise impacts may be lower than predicted.

Implementation of mitigation and management measures, as detailed in Section 7 of Appendix G (Technical report – Noise and vibration) of the EIS, would be essential to minimise health-related impacts due to construction activity. This includes the development and implementation of a CNVMP as detailed in Appendix G (Technical report – Noise and vibration) of the EIS. Following the implementation of all reasonable and feasible mitigation measures, additional measures may need to be implemented to manage residual noise and vibration impacts (refer to Section 7 of Appendix G (Technical report – Noise and vibration) of the EIS), and to minimise potential health impacts.

The project has the potential to generate noise at levels that exceed health-based noise criteria during works conducted during standard operating times and for night-time operations. While the potential for impacts on health will be variable due to the relative short-term nature of the noise activities, noise mitigation measures are required to be implemented to mitigate noise, particularly adjacent to construction sites. Where mitigation measures are implemented the potential for health impacts from noise during construction may be low to moderate, depending on the mitigation measures implemented. Effective communication of noise activities is important in managing such impacts on the community.

7.6.3 Operational noise

Road noise

The operational noise assessment identified that 30 receptors are expected to experience noise in excess of the adopted noise criteria. In addition, road noise levels would reduce at a significant number of sensitive receptors (around 2,000) where the tunnel provides a bypass to the existing surface road. Noise levels would increase on the upgraded sections of the Great Western Highway where traffic volumes would be expected to increase. For the majority of receptors impacted by increased levels of road noise, the change in noise levels is less than two dB(A) due to the project, which is unlikely to be discernible or impact on health.

Noise levels are predicted to increase by more than 2 dB(A) at one sensitive receiver.

There are two receptors (located at Little Hartley) where noise levels are predicted to equal or exceed the cumulative limit (ie ≥ $L_{Aeq(15\ hr)}$ or $L_{Aeq(9\ hr)}$ noise criterion + 5 dB(A)). These receptors are considered to be eligible for the consideration of feasible and reasonable noise mitigation measures. One of these receptors has already been identified for consideration of noise mitigation measures as part of the Great Western Highway Little Hartley to Lithgow Upgrade (West Section). Noise walls at Little Hartley not considered reasonable given the low number of receptors that warrant noise mitigation in this area. Hence noise mitigation is expected to include consideration of low noise pavement and/or at-property treatment.

From a health perspective, where at-property treatment is required to minimise noise exposures (in excess of relevant guidelines), the following should be considered:

- where specific individuals do not take up the recommended at-property treatments, there is the potential for road traffic noise to result in adverse health effects including increased levels of noise annoyance and sleep disturbance
- the implementation of at-property treatments may impact on individual use of outdoor space, where available on an individual property. This is not an issue for residential units, however where at-property treatments relate to low-medium density residential homes such as the two properties identified at Little Hartley, this may impact on use of outdoor areas. Impacts on the use and enjoyment of outdoor areas due to increased noise may result in increased levels of stress at individual properties.

Similarly, from a health perspective, where low noise pavement is installed to mitigate noise, it is important to ensure that such pavement is appropriately maintained to ensure noise levels do not increase over time.

No noise sensitive receptors have been identified as being acute, i.e. there are no noise levels during day/evening period (i.e. ≥ $L_{Aeq(15\ hr)}$) that exceed 65 dB(A) and no noise levels during the night-time period (i.e. $L_{Aeq(9\ hr)}$) that exceed 60 dB(A)).

The assessment conducted identified that the study area is already exposed to maximum noise level events that have the potential for awakening reactions (sleep disturbance), with a lower potential for these events to occur as a result of the project due to reduced congestion on surface roads. A lower potential for sleep disturbance would be of some health benefit to the community.

Overall, the number of properties where increases in noise at levels that may be of concern to health as a result of the project is very small (limited to two properties). Where noise mitigation measures proposed are implemented, no significant health impacts are expected for these properties.

For the majority of the community along the existing surface road corridor, road noise impacts would be reduced as a result of the project, resulting in some health benefits.

Fixed facilities

In relation to the portal emissions option, there is the potential for up to one receptor to experience increased levels of noise that exceed the adopted noise criteria during normal and low flow traffic conditions. During emergency conditions 14 receptors may experience increased levels of noise from the operation of the fire pump.

In relation to the ventilation outlet option, there is the potential for up to four receptors to experience increased levels of noise that exceed the adopted noise criteria during normal and low flow traffic conditions. During emergency conditions 19 receptors may experience increased levels of noise from the operation of the fire pump.

For both ventilation options, the noise impacts during normal and low flow traffic conditions relate to the operation of jet fans near the portal exits. To mitigate this noise, quieter jet fans could be selected, or the use of attenuators could be investigated. Where the noise levels are mitigated during normal operations there would be no changes in noise that would adversely impact on community health.

Summary

The operation of the project would result in reduced noise levels at a substantial number of sensitive receptors where the tunnel provides a bypass to the existing surface road. Noise levels would increase on the upgraded sections of the Great Western Highway where traffic volumes would be expected to increase. The increase in noise levels predicted would not be of concern to community health, with the exception of two receptors in Little Hartley where nose mitigation measures would be required to managed noise, and health impacts.

Noise impacts from fixed facilities would require management to ensure noise criteria were met close to the portals (regardless of the ventilation design adopted).

7.7 Summary of outcomes – noise and vibration

The assessment undertaken in relation to health impacts that may occur due to changes in noise and vibration resulting from the project has concluded:

- construction:
  - the project has the potential to generate noise at levels that exceed health-based noise criteria during works conducted during standard operating times and for night-time operations. While the potential for impacts on health would be variable due to the relative short-term nature of the noise activities, noise mitigation measures are required to be implemented to mitigate noise, particularly adjacent to construction sites
  - where mitigation measures are implemented the potential for health impacts from noise during construction may be low to moderate, depending on the mitigation measures implemented. Effective communication of noise activities is important in managing such impacts on the community
  - however, it is expected that some individuals within the community may find construction noise annoying at times, even with mitigation. The management of noise impacts during construction needs to include a notification and complaints system

- operation:
  - the operation of the project would result in reduced noise levels at a substantial number of sensitive receptors where the tunnel provides a bypass to the existing surface road. Noise levels would increase on the upgraded sections of the Great Western Highway where traffic volumes would be expected to increase. The increase in noise levels predicted would not be of concern to community health, with the exception of two receptors in Little Hartley where nose mitigation measures would be required to managed noise, and health impacts
  - noise impacts from fixed facilities would require management to ensure noise criteria were met close to the portals (regardless of the ventilation design adopted).

Section 8. Public safety and contamination

8.1 General

This section provides a review of the potential risks posed to public safety, associated with the project. This section also presents a review of health impacts associated with the presence and management of contamination (in soil, surface water and groundwater) relevant to the project.

This section only addresses risks to the community, i.e., risks that only have the potential to adversely affect the community. Issues relevant to workplace health and safety during construction (including contamination remediation) and operation have not been further discussed or addressed.

8.2 Public safety

8.2.1 Construction

A range of potential hazards have been identified that have the potential to affect public safety during construction. These are outlined in **Table 8-1**, along with discussion on the risks that may be posed by these hazards. Not all the hazards identified in the hazard and risk assessment have been included in the table, only those where there is the potential for risks to public safety.

On the basis of the information provided in **Table 8-1** there are no issues related to construction that have the potential to result in significant safety risks to the community.

Table 8-1: Overview of public safety hazards and risks: Construction

Hazard: Public safety	Risk to public safety	Management measures
Storage and handling of dangerous goods on construction sites that may impact on the off-site community	Low The storage would comply with screening thresholds prescribed under SEPP 33.	Store all materials in accordance with the Australian Dangerous Goods Code of Practice, including limiting amounts stored, use of bunding, ventilation of areas where gases are stored, locating stores of these materials away from sensitive areas, and maintaining a register and inventory.
Transport of dangerous goods and hazardous substances on public roads within the community	Low The quantities and frequency of transport for these chemicals is low and within prescribed thresholds.	Transport all materials in accordance with relevant standards, codes and practices.
Bushfire or fire risks that may spread off-site and affect neighbouring properties or affect visibility on existing roads	Medium to high prior to mitigation and controls Low to medium after implementation of mitigation and controls	The project would be located in close proximity to bushfire prone land. For these sites, it is relevant to develop a site specific bushfire risk assessment that considers and accounts for site layout, setbacks, access and emergency procedures. A range of mitigation measures have been identified for implementation during further design development to minimise project related changes to bushfire risks. A bushfire management plan will be prepared as part of the Construction Environment Management Plan to ensure all aspects of managing bushfire risk during construction are considered and managed. This includes appropriate community consultation and using a permit system for hot work to ensure weather conditions are considered on all occasions.

Hazard: Public safety	Risk to public safety	Management measures
		This plan will be reviewed by NSW Fire and Rescue and NSW Rural Fire Service to ensure it is appropriate and comprehensive.
Damage to underground utilities (e.g. water, sewage, electricity, gas or communications), during construction of the tunnel affecting services provided to the community	Low	Utility checks (including dial-before-you-dig searches and non-destructive digging) and consultation with relevant utility providers during design development and during construction will be undertaken to confirm the location of underground utilities and services. Relocation, protection or removal of utilities in and around the project would be undertaken, if required. In particular, appropriate protection of the 132kV cable running along the existing Great Western Highway has been incorporated into the project.
Intercepting gas in coal seams	Moderate	The project involves tunnelling through areas which include coal measures – i.e. there are coal seams in the geology through which the tunnelling would occur. It is possible that coal seam gas (i.e. methane) may be present in such areas which may move out of the coal seams into the areas where tunnelling is occurring. If sufficient methane accumulates in a space, an explosive risk is possible. A detailed site investigation would be undertaken prior to the works commencing which would outline where coal seam gas might occur. If this work indicates that a sufficient quantity to cause issues for workers might exist, then infrastructure to drain and vent such gas away from the tunnelling and away from work areas would be installed. Such investigations and infrastructure are well understood and accessible.
Ground movement including subsidence, that may affect community areas overlying the tunnel	Low	Geotechnical and ground movement investigations have been carried out for the various stages of this project to consider potential for impacts to private property, road and rail infrastructure and utilities. The tunnels have been designed to ensure all estimated settlement due to tunnelling is in compliance with the requirements of all relevant guidance. This work has identified around 24 residential properties and around seven heritage properties/items which required additional investigation. The detailed analysis did not identify any residential properties where estimated settlement was not in compliance with relevant guidelines. The detailed analysis for utilities showed that for most situations the pipes used for water and sewer mains would not be impacted by settlement due to this tunnelling. One type of pipe (cast iron concrete lined) used for water mains was shown to have potential to be impacted by these works. As a result, a specific assessment of the characteristics of those pipes in the most affected areas (i.e., depth of pipe, age of pipe, soil characteristics etc) will be required as part of the detailed design for the project and/or these types of pipe in the most affected locations should be monitored during works. Detailed assessment of the potential for rail and road infrastructure to be impacted by settlement did not identify any locations where conservative

Hazard: Public safety	Risk to public safety	Management measures
		calculations indicated a likelihood of issues. Monitoring of rail infrastructure during works was still recommended. A detailed monitoring plan would be included in the Construction Environmental Management Plan.
Public safety issues	Low	Rock falls – standard measures would be applied during the project to ensure risks to workers or the community are minimised including use of appropriate personal protective equipment, frequent inspections of tunnelling works, appropriate installation of ground supports, safety fencing and overhead protection measures. Operation of mobile plant and machinery – just as in any construction project, there is potential for impacts on workers (and potentially on the community) due to issues with mobile plant. Standard measures will be implemented to ensure best practice management of such equipment including development of a full work health and safety plan and the use of safe work method statements for each type of construction activity.
Acid sulfate soils, that may result in acidification and the mobilisation of metals, adversely impacting groundwater that can then migrate off-site	Low Area is classified as predominantly class C or B for acid sulfate soils – i.e. that is low to extremely low probability of such soils being present.	Develop acid sulfate management measures to mitigate the potential risks associated with the disturbance of acid sulfate soils should any be identified in the geotechnical investigations. This requirement would be included in the Construction Environmental Management Plan.

8.2.2 Operations

A range of potential hazards have been identified that have the potential to affect public safety during the operation of the project. These are outlined in **Table 8-2**, along with discussion on the risks that may be posed by these hazards. Not all the hazards identified in the hazards and risk assessment have been included in the table, only those where there is the potential for risks to public safety.

On the basis of the information provided in **Table 8-2,** there are no issues related to the operation of the project that have the potential to result in significant safety risks to the community.

Table 8-2: Overview of public safety hazards and risks: Operation

Hazard: Public safety	Risk to public safety	Management measures
Storage, handling and transport of dangerous goods required for maintenance of the project, that may impact on the off-site community	Low The storage requirements are minor, with limited and infrequent transport of these materials required.	Store and transport all materials in accordance with the relevant legislation and codes.
Transport of dangerous goods and hazardous substances in project tunnels	Low A decision on whether dangerous goods transport would be allowed to travel through the tunnel would be made during ongoing design development. The capacity of fire and life safety measures to manage potential dangerous good incidents would be confirmed.	Provide signage near tunnel entry portals advising of the restrictions to ensure compliance.

Hazard: Public safety	Risk to public safety	Management measures
Bushfires	Low	Once the project has been completed, the project would minimise impacts relating to bushfires by: - considering the introduction of regular organic fuel management to reduce bushfire risk around the project site - project landscaping would apply bushfire protection zones using non-woody vegetation - assist traffic management during fire emergencies as it would provide an additional route through the area that is less likely to be impacted by such fires. In regard to bushfire smoke, the tunnel ventilation system would work to keep the air quality within the tunnel appropriate for use. However, if excess levels of bushfire smoke could be present in the tunnel, then the tunnel would be shutdown to prevent exposure to such smoke for people using the tunnel. The materials used to construct the tunnel that would be in locations that could be fire prone would not be materials that are vulnerable to bushfire – they would be of appropriate quality as defined by relevant guidance from NSW Rural Fire Service or appropriate Australian Standards.
Coal seam gas	Moderate	While the potential for encountering coal seam gas during construction has been discussed above, the potential for ongoing management of methane in tunnel infrastructure requires further assessment. It is expected that the tunnel ventilation requirements would be sufficient to mitigate hazards posed by coal seam gas (specifically methane) within the tunnel. However, the potential for methane to migrate into and accumulate in confined spaces within the tunnel such as pedestrian cross-passages, worker corridors and plant/equipment rooms requires further investigation and assessment. Should methane be identified as a risk for these confined spaces, gas mitigation measures would need to be designed and constructed to ensure explosive risks during operations are appropriately mitigated.
Traffic accidents (including pedestrian and cycle safety)	Low to moderate (however, the risk is considered to be reduced with the project). All use of public roadways carries an inherent risk of vehicle collision. The project has been designed to minimise these risks for travel within the tunnels.	The project design incorporates all feasible and reasonable traffic safety measures including in relation to geometry, pavement, lighting and signage, pedestrian and cyclist facilities, consistent with current Australian Standards, road design guidelines and industry best practice. The project has been designed to meet appropriate fire and life safety requirements in the tunnel. The project would involve a reduction in traffic demand on some roadways, which has the potential to reduce crash rates, and improve pedestrian and cyclist safety.

8.3 Contamination

8.3.1 General

A desktop investigation has been undertaken to determine the potential for impacts to human health from contamination within the project footprint. The investigation has included a review of site history reports for the project footprint which indicate the presence of common contaminating activities such as service stations, drycleaning facilities, vehicle repair facilities or fire stations. While a number of such facilities have been identified as being present within the footprint, none are close to the areas where surface works would occur – i.e., near the construction sites. The closest site with such a contaminating activity is a service station at Little Hartley. This site is more than 700 metres to the northwest of the construction footprint so is unlikely to be impacted by these works.

Should unexpected contamination be identified in soil or water during the early stages of works, a range of actions will be required as per government requirements to determine potential for risks to health and the need for remediation. These requirements apply regardless of when such contamination is identified.

8.3.2 Soil

For soil with contamination to have the potential to impact human health, people must be able to come into direct contact with the soil or with vapours that might come off those soils.

Risks due to such exposure are expected to be low for this project due to:

- surface works are being undertaken in locations where no contaminating activities have been identified
- tunnelling would be through bedrock which has limited potential to be contaminated due to its nature and the depth at which it is located
- surface works would be undertaken within construction sites to which the general public will not have access so the public cannot be directly exposed to such soils should any currently unidentified contamination be found during initial works
- workers within the construction sites and within the tunnels have potential to come into direct contact with soils or vapours from soils but normal personal protective equipment (PPE) for construction (i.e., long pants, long sleeves, boots) and use of mechanical equipment to undertake many of the works (e.g., tunnel boring machines) will limit such exposure.

Where works are undertaken in areas without soil contamination, this project does not change the potential for impacts from contamination to human health.

Where areas with soil contamination are located within the project footprint but in areas where no surface works are proposed, this project does not change the potential for impacts from contamination to human health.

There are standard minimum standards required by government which the project would need to comply with for the management of soil at such sites.

8.3.3 Groundwater

Groundwater is the water that accumulates within the ground – in the cracks and pores in the rocks, sands and soil.

The tunnels would pass through bedrock for most of the project. This means there would be limited amounts of groundwater within the bedrock (due to limited cracks and pores) and the potential for such groundwater to be contaminated by contaminating activities at the ground surface will also be low as it would be difficult for contamination to reach such depths.

Available information has not indicated that shallow groundwater near the construction sites is particularly contaminated. These are the only locations where such groundwater might be encountered. This is supported by the findings that no contaminating activities were identified as occurring in those areas.

The tunnel construction involves use of TBMs that allow for the tunnel lining (waterproof lining) to be installed at the same time as tunnel excavation occurs. This limits the ingress of groundwater during these tunnelling activities. Any groundwater that is extracted from the subsurface during tunnelling works and from around the tunnel during operation must be treated via the water treatment plants that would be located at each construction site. Such water may contain sediment/soil during the tunnelling works. Standard water treatment plants would be appropriate for removal of sediment/soil from the extracted groundwater. Should any additional, unexpected contaminants be identified during initial works, such plants are usually able to be upgraded to address other contaminants.

People can come into contact with groundwater only once it comes out of the ground. Groundwater could only be encountered at the construction sites to which the general public have no access. Exposure to workers will be limited as the water will be directed toward the treatment plants so workers are likely to be exposed after the water is treated to an appropriate standard as per government requirements.

It is not expected that the works will result in contamination of the groundwater that remains in the ground, given understanding of the tunnelling process for other major road and rail infrastructure across NSW.

There are standard minimum standards required by government which the project will need to comply with for the management of groundwater.

8.3.4 Surface water

Impacts on surface water from this project can only occur from runoff from the construction sites. Normal requirements for managing such sites include collecting stormwater that might fall on areas which could be impacted by equipment or some level of contamination for treatment prior to discharge. Stormwater that may fall onto undisturbed areas of these sites is usually allowed to runoff into surface drainage lines without treatment.

Such systems would be appropriate for this project. The operation of such stormwater management systems at these sites would be detailed in the Construction Environmental Management Plan to ensure the design is appropriate.

There are standard minimum standards required by government which the project will need to comply with for the management of stormwater.

During operation, groundwater seepage, stormwater drainage at tunnel portals, tunnel wash-down water, fire suppressant deluge or fire main rupture and spillage of flammable and other hazardous materials would be captured by tunnel drainage. The captured water would be treated and discharged to the receiving water bodies where it cannot be reused by the project.

Where surface water is managed as summarised above there are no project related impacts that would be considered to be of concern to community health.

8.4 Summary of outcomes – public safety and contamination

Overall, during construction the potential for project related activities to be of concern in relation to public safety and health (from contamination) is considered low to moderate. Moderate risks (relating to coal seam gas and bushfires) can be effectively managed to mitigate the risks identified.

The potential for the project operations to be of concern in relation to public safety and health (from contamination) is considered low to moderate. Moderate risks relate to coal seam gas, which requires further assessment and mitigation (where required) and road safety, noting that the project is expected to result in an improvement in road safety from the existing situation.

Section 9. Assessment of other changes on health

9.1 General

The World Health Organisation defines health as 'a (dynamic) state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity'. The assessment of health should thus include both the traditional and medical definition that focuses on illness and disease as well as the more-broad social definition that includes the general health and wellbeing of a population.

The assessment of changes in air quality and noise on the health of the local community (presented in **Section 5**, **Section 6** and **Section 7**) addressed key aspects that have the potential to directly affect health.

There are, however, a range of other impacts associated with the project that can affect the health and well-being of the community in a more indirect way. In addition, changes within a community that may be associated with the project may be differentially distributed. This may affect population groups that may be advantaged or disadvantaged based on age, gender, socioeconomic status, geographic location, cultural background, aboriginality, and current health status and existing disability. This aspect relates to the equity of the impacts in the local community.

This section more specifically evaluates changes in the community that have the potential to indirectly affect the health and wellbeing of the community. In addition, this section provides a review of whether there are any impacts likely to be more significant in any section of the community, and if these areas may result in inequitable impacts on the health of the population.

The evaluation presented in this section provides a qualitative evaluation of potential health impacts on the community.

This assessment has drawn on information provided in a number of EIS Technical reports (as referenced) and, in some areas, provides a summary of key (and relevant) aspects. All details relevant to the underlying assumptions, methodology and interpretation of impacts are provided within these technical reports. Where more detail than provided in the health impact assessment is required, the reader is directed to the individual technical reports.

9.2 Changes in traffic, access and connectivity

9.2.1 Construction

Temporary disruptions in access to work, recreation, local shops, community facilities and essential services may occur due to temporary changes to traffic arrangements during construction. Consultation during development of this EIS, specifically the SIA consultation activities (refer to Appendix O (Technical report – Social) of the EIS for further detail) identified that people living in the study area have a high reliance on private vehicle transport and that measures to manage construction traffic and access impacts were important for this project.

The following temporary changes to the transport network may disrupt people's ability to get around their local area:

- there would be a need for temporary modifications to the Great Western Highway and intersections immediately adjacent to construction sites to maintain the functionality of surrounding roads and to protect the safety of all road users, including pedestrians, cyclists, motorists, public transport users and construction personnel

- temporary traffic modifications would be staged so as to not impact traffic movements unnecessarily and to maintain a minimum of one lane in each direction of traffic movement
- issues related to the construction traffic which would need to use the Great Western Highway where construction haul routes are proposed. Construction haul routes would be along the Great Western Highway, to minimise the presence of heavy vehicles on local roads. Site access for heavy vehicles would target the Great Western Highway, rather than introducing heavy vehicles to local roads.

Social infrastructure like schools, childcare, health care facilities and recreation areas are mainly located within town centres. Access to these facilities is unlikely to be substantially disrupted as the construction footprint avoids these areas. There is one location which may have small disruption in an area near Browntown Oval. This location is adjacent to the Soldiers Pinch construction site and may be impacted by movement of heavy construction vehicles, worker parking and equipment storage. Works will be designed to manage these impacts.

9.2.2 Operational

The impact of the project once operational would be beneficial as the project would divert a substantial proportion of through traffic from surface roads into the tunnels. This means the surface roads will be left to mostly cater to local users. This should substantially improve local movements.

Access to social infrastructure is likely to be improved once the project is operational due to the improvement in movement around the area with less traffic congestion on the surface roads.

9.2.3 Public transport

Public transport is important for the whole community in terms of its contribution to a liveable neighbourhood. Access to public transport is important, particularly for people who cannot or are unable to drive (such as the elderly and those with disabilities). Lack of good access to public transport for these individuals can result in increased feelings of isolation, helplessness and dependence.

Once the project is operational, no specific impacts on public transport are expected, other than benefits due to decreased travel times for buses on surface roads and/or within the tunnel system for through trips.

9.2.4 Pedestrian and cycle access

Walking and cycling have many health benefits including maintaining a healthy weight and improved mental status (Hansson et al. 2011; Lindström 2008; Wen & Rissel 2008; WHO 2000b).

Construction works have been focused in areas away from the major town centres to ensure minimal interaction between heavy vehicles and pedestrians/cyclists. While there are limited formal pedestrian/cycling paths in the areas further from the town centres where the works would occur, the Katoomba to Blackheath Upgrade and Little Hartley to Lithgow Upgrade include development of active transport linkages near Blackheath and Little Hartley. Any changes to existing road shoulders etc where people walk or ride would be temporary and their implementation and management will be included in the Construction Traffic Management Plan.

No specific improvements to pedestrian and cycling facilities are proposed for this project (noting that the improvements proposed relate to the Katoomba to Blackheath Upgrade and Little Hartley to Lithgow Upgrade projects). Reduced traffic congestion on the surface roads would make the use of road shoulders etc for cycle paths less problematic. Further investigation of other opportunities to improve such infrastructure will be considered by Transport for NSW in consultation with local Councils.

9.3 Property acquisition

The acquisition and relocation of households and businesses due to property acquisition (particularly where individuals feel they have no say in the acquisition) can disrupt social networks and affect health and wellbeing due to raised levels of stress and anxiety. This includes increased levels of stress and anxiety during the process of negotiating reasonable compensation. The purchase of and moving into a house can be one of the most significant events in a person's life. Both a house and a workplace are central to daily routine with the location of these premises influencing how a person may travel to/from work or study, the social infrastructure and businesses they visit and the people they interact with. The displacement of businesses has the potential to impact on local employment opportunities. Further discussion on stress and anxiety is presented in **Section 9.8.**

This project has been designed to minimise the need for private property acquisition. This has been possible due to the use of tunnelling to provide the additional road infrastructure. However, the project does require some property acquisition as well as other temporary/permanent impacts on land use. In areas where this might be required, community consultation has identified that many living in those areas were long term residents having lived in those locations for 10 or more years. These areas were not reported to be in socially disadvantaged parts of the community.

The project would require the acquisition of property owned by two landowners in the area of Little Hartley, with one partial construction lease required at the Soldiers Pinch construction site.

In addition, the construction and operation of the project would require the acquisition of land below the surface of the ground to accommodate the tunnels (substratum acquisition). In some circumstances, the introduction of the tunnels has the potential to limit development above the tunnels. However, given the existing land use of the area and potential for future development particularly around the tunnel portals, this impact is considered unlikely.

Temporary use of properties would be managed through leasing arrangements or property acquisition should lease arrangements not be practical. Where required, discussions would be held with affected property owners concerning the purchase, lease, or licence of land. Landowners and tenants of landowners affected by acquisition would be supported by access to counselling services throughout the process and a community relations support toll-free telephone line would be established to respond to any community concerns.

All acquisition required for the project would be carried out in accordance with the Land Acquisition (Just Terms Compensation) Act 1991 and the Land Acquisition Information Guide (NSW Government 2014). Relocation and some other categories of expenses would be claimable under this Act.

Even with these support services in place, relocation of people whose property needs to be acquired may be more difficult than for some other road infrastructure projects particularly those in metropolitan Sydney, due to the limited availability of properties in the Blue Mountains for such people to purchase or rent.

9.4 Visual and landscape changes

Visual amenity can be described as the pleasantness of the view or outlook of an identified receptor or group of receptors (e.g., residences, recreational users). Visual amenity is an important part of an area's identity and offers a wide variety of benefits to the community in terms of quality of life, wellbeing and economic activity. For some individuals, changes in visual amenity can increase levels of stress and anxiety and may affect the use of outdoor spaces for walking and cycling. These impacts, however, are typically of short duration as most people adapt to changes in the visual landscape. It is noted that revegetation may take longer to be restored, however, visual changes of revegetation are not considered to impact on the wellbeing of the community. As a result, most changes in visual impacts are not expected to have a significant impact on the health of the community.

Appendix N (Technical report – Urban design, landscape and visual) of the EIS provides an assessment visual impact of the project.

The greatest impacts relate to the design scenario where emissions are discharged via ventilation outlets (at Blackheath and Little Hartley). The scale and position of the proposed ventilation outlet would result in an adverse impact on the quality of the landscape character. Other elements of the project (other than the ventilation outlets) are more typical within the transport corridor setting and are not considered to be adverse.

Where the design incorporates portal emissions there are no adverse impacts identified in terms of landscape character at Blackheath, with the changes more typical within the transport corridor setting which are not considered to be adverse. However, at Little Hartley the tunnel portals and infrastructure (substation, water pumping station and switching stations) would comprise a substantial change in the built forms in the landscape that are considered to be adverse.

Overall impacts on the landscape character are considered to be moderate to high, however these impacts are localised.

During construction vegetation clearing would comprise the most substantial change at Blackheath. These impacts are lower in the more open, rural area of Little Hartley. Views to the construction sites would be seen for the approximate eight year construction period. During operations visual impacts are considered to be moderate at Blackheath and Little Hartley.

While it is noted that the existing character of the Blue Mountains area is considered to have a high landscape value and some individuals may be more sensitive to the changes associated with any major infrastructure project. Proposed tree plantings in the areas of the portals would reduce the visual impacts over time. However, such changes may result in some increased level of stress and anxiety for some individuals, particularly when the project commences operations and the changes are new. Further discussion on stress and anxiety is presented in **Section 9.8.**

9.5 Green space

Green space includes bushland, grassland, parks and gardens, green corridors (paths, rivers and canals), outdoor sporting facilities, playing fields and children play areas. At a fundamental level there are links between human health/wellbeing and nature/biodiversity (Brown & Grant 2005; EC

2011a; WHO 2015). This is particularly important in urban settings where green space areas are limited, however the links remain relevant to all settings including the towns and rural residential areas located within the study area.

Epidemiological studies have been undertaken that show a positive relationship between green space and health and wellbeing (de Vries et al. 2003; Health Scotland 2008; Kendal et al. 2016; Maas et al. 2006; Mitchell & Popham 2007). The outcomes of these international studies depend on the quality of the available green space.

The health benefits of green space include the following (Health Scotland 2008; Kendal et al. 2016; Lee & Maheswaran 2011; Rozek et al. 2018):

- green space areas, that include large trees and shrubs can protect people from environmental exposures associated with flooding, air pollution, noise and extreme temperature (by regulating microclimates and reducing the urban heat island effect)
- reduced morbidity and mortality
- improved opportunities for physical activity and exercise
- improved mental health and feelings of wellbeing, particularly lower stress levels and the perception of restorative effects
- improve opportunities for social interactions.

The location of the project is in an area with access to significant areas of green space with the Blue Mountains National Park, and a number of other parks and sporting fields located in the area. The project is designed to minimise potential impacts on existing green space, specifically Browntown Oval. The Blackheath construction footprint would require use of land previously part of the national park and nature reserve area. The Soldiers Pinch construction footprint is close to Browntown Oval, however the proposed works would not impact on recreational use of the oval. These areas would be returned for recreational use following completion of construction. Given the extensive size of the national park, conservation and nature areas, the changes due to the project are not expected to impact on green space or the passive and active recreational use of green space in the study area. Hence no impacts on health are expected.

9.6 Equity issues

The health effects associated with impacts related to transport projects are not equally distributed across the community. Groups at higher risk, or more sensitive to impacts, include:

- elderly (which is considered to be those over 65 years in this assessment)
- individuals with pre-existing health problems
- infants and young children
- individuals with disabilities
- individuals who live in areas of higher levels of air or noise pollution.

Often the impacts can accumulate in the same areas, which may already have poorer socioeconomic and health status, most commonly due to the affordability of housing in areas that are closer to main roads, industry or rail infrastructure. Disadvantaged urban areas are commonly characterised by high traffic volumes, higher levels of air and noise pollution, feelings of insecurity and lower levels of social interactions and physical activity in the community.

To further evaluate potential equity issues associated with the project, the location of impacts identified in relation to air quality, noise and traffic were reviewed individually and in combination, in conjunction with available information on the location of sensitive community groups.

The surface works are located in areas where few people live or work – i.e., in areas between the townships along the highway. This means the majority of the impacts during construction are not in areas of social disadvantage.

Where construction noise is mitigated, the potential for impacts from changes in air quality and noise to pose an increased risk to community health is considered to be low, for receptors located close to the construction works.

During operation of the project, the reduction in traffic congestion along the surface roads should assist all those living in the project area, due to reduced congestion on surface roads and reduced travel times.

9.7 Economic aspects

9.7.1 Construction

The construction expenditure for this project would result in a significant increase in economic activity. This expenditure would inject economic stimulus benefits into the local, regional and state economies. Ongoing or improved economic vitality is of significant health benefit to the community. Employment opportunities would grow in the region through the potential increase in business customers and through the increase in demand for construction workers. The increase in demand for labour may increase wages in the region, particularly for construction workers, who would be in high demand.

Based on the expected capital expenditure profile during construction, it is estimated that the project could increase the gross output of the regional area by around $300 million a year over the construction period, resulting in an annual boost of around $130 million to the gross regional product and supporting a large number of additional jobs a year over the construction period. Increased employment is a significant benefit to community health.

The community has raised a number of key concerns including:

- adverse traffic congestion and travel time impacts, for example, increased trucks on the road, lane closures causing traffic build up
- adverse construction noise impacts, for example, increased trucks on the road, general construction noise, night-time construction
- adverse access and connectivity impacts, for example, road closures, impacts on escape routes during emergencies, property and business access.

It is noted that, as a result of these impacts, the project may negatively affect local business activity during the construction phase of the project. However, this is expected to be a short term impact and is not expected to cause a significant impact on the overall activity of local businesses.

9.7.2 Operation

It is expected that there will be ongoing economic impacts/benefits to the regional economy via the three drivers shown in **Figure 9-1**.

Figure 9-1: Key economic drivers during operation

In the first ten years, once the project becomes operational, it is estimated that the project will increase total gross output in the regional study area by an average of around $15 million a year, with total value added in the region increasing by around $8 million a year. In terms of employment impacts, the project is expected to support additional jobs in the regional area which includes both direct and indirect jobs. Increased employment is a significant benefit to community health.

It is also expected that traffic congestion/travel times for travel between Blackheath and Little Hartley will improve once the project is operational – for through traffic and local traffic. This should improve productivity for local businesses. It may also improve access to jobs for local residents due to ease of travel.

The community also indicated that improving the traffic congestion may help with the connectivity in these communities due to decreased issues with traffic, accidents etc. This may improve local access to health care facilities as well as to green space (including National Park) and sporting facilities. Improving connections within communities as well as ability to access the full range of community facilities and green space helps mental and physical health.

Reducing the levels of traffic on the Great Western Highway by moving traffic to the tunnels has the potential to improve land value over time due to improved amenity around the Highway. It is also possible that new businesses will move to the new areas around the bypass areas.

9.8 Stress and anxiety

A number of changes within the community have the potential to affect levels of stress and anxiety. Some changes may result in a lowering of feelings of stress and anxiety, and there are others that may result in higher levels within the community.

Chronic and persistent negative stress, or distress, can lead to many adverse health problems including physical illness and mental, emotional and social problems. Response to stress varies between individuals with genetic inheritance and personal/environmental experiences of importance (Schneiderman, Ironson & Siegel 2005).

An acute stressful event results in changes to the nervous, cardiovascular, endocrine and immune systems, more commonly known as the “fight or flight” response (Schneiderman, Ironson & Siegel 2005). Unless there is an accident or other significant event, such acute stress events are not expected to be associated with construction or operation of the project.

For shorter-term events, stress causes the immune system to release hormones that trigger the production of white blood cells that fight infection and other disease-fighting elements. This response is important for fighting injuries and acute illness. However, this activity within the body is not beneficial if it occurs for a long period of time. Hormones released during extended or chronic stress can inhibit the production of cytokines (the messengers that allow cells to talk together to fight infection) lowering the body's ability to fight infections. This makes some individuals more susceptible to infections and may also experience more severe infections. It can also trigger a flare up of pre-existing autoimmune diseases (which are a range of diseases where the immune system gets confused and starts attacking healthy cells) (Mills, Reiss & Dombeck 2008; Schneiderman, Ironson & Siegel 2005).

- other physiological effects associated with chronic stress include (Brosschot, Gerin & Thayer 2006; McEwen, Bruce S. 2008; McEwen, B. S. & Stellar 1993; Mills, Reiss & Dombeck 2008; Moreno-Villanueva & Bürkle 2015)
- digestive disorders, with hormones released in response to stress causing a number of people to experience stomach ache or diarrhoea, with appetite also affected in some individuals (resulting in under-eating or over-eating)
- chronic activation of stress hormones can raise an individual's heart rate, cause chest pain and/or heart palpitations and increase blood pressure and blood lipid (fat) levels. Sustained high levels of cholesterol and other fatty substances can lead to atherosclerosis and other cardiovascular disease and sometimes a heart attack (Pimple et al. 2015; Seldenrijk et al. 2015)
- cortisol levels, release at higher levels with stress, play a role in the accumulation of abdominal fat, which has been linked to a range of other health conditions
- stress can cause muscles to contract or tighten, cause tension aches and pains (Ortego et al. 2016).

Some individuals respond to elevated levels of stress by taking up or continuing unhealthy stress coping strategies such as smoking, drinking or overeating, all of which are associated with significant health risks. Chronic levels of stress have also been found to cause or exacerbate existing mental health issues, including mood disorders such as depression and anxiety, cognitive problems, personality changes and problem behaviours. It can also affect individuals with pre-existing bipolar disorders.

By-products of stress hormones can act as sedatives (chemical substances which cause us to become calm or fatigued). When such hormone by-products occur in large amounts (which would happen under conditions of chronic stress), they may contribute to a sustained feeling of low energy or depression. Habitual patterns of thought which influence appraisal and increase the likelihood that a person would experience stress as negative (such as low self-efficacy, or a conviction that you are incapable of managing stress) can also increase the likelihood that a person would become depressed. It is normal to experience a range of moods, both high and low, in everyday life. While some "down in the dumps" feelings are a part of life, sometimes, people fall into depressing feelings that persist and start interfering with their ability to complete daily activities, hold a job, and enjoy successful interpersonal relationships (Mills, Reiss & Dombeck 2008; Schneiderman, Ironson & Siegel 2005).

Some people who are stressed may show relatively mild outward signs of anxiety, such as fidgeting, biting their fingernails, tapping their feet, etc. In other people, chronic activation of stress hormones can contribute to severe feelings of anxiety (e.g. racing heartbeat, nausea, sweaty palms, etc.), feelings of helplessness and a sense of impending doom. Thought patterns that lead to stress (and depression, as described above) can also leave people vulnerable to intense anxiety feelings (Mills, Reiss & Dombeck 2008).

Anxiety or dread feelings that persist for an extended period of time; which cause people to worry excessively about upcoming situations (or potential situations); which lead to avoidance; and cause people to have difficulty coping with everyday situations may be symptoms of one or more anxiety disorders (Mills, Reiss & Dombeck 2008).

More generally, it must be noted that urbanisation, or increased urbanisation, regardless of specific projects has been found to affect levels of stress and mental health (Srivastava 2009). These impacts are greater where there is urbanisation without improvements in infrastructure to improve equitable access to employment and social areas/communities (Srivastava 2009).

The role of either acute or long-term environmental stress on the health of any community, in general and for specific project(s), including the project, cannot be quantified. There are a wide range of complex factors that influence health and wellbeing, specifically mental health. It is not possible to determine any specific outcomes that may occur as a result of a specific project, or number of projects. However, it is noted that within any suburban/rural environment there would be a wide range of stressors present that may or may not contribute to the health effects outlined above.

Many of the impacts identified that may result in changes in levels of stress and anxiety relate to short-term impacts during construction (noise, visual and traffic changes) that may be able to be managed by individuals with minimal impact on health. Where construction impacts are extended, as may be the case for receptors located close to construction sites these changes may be prolonged and hence there is the potential for increased levels of stress and anxiety to impact on health, where coping mechanisms are not adequate. Once operational, there may be some increased levels of stress and anxiety due to the change in visual character and the operation of the ventilation system (perceived changes), however the reduced levels of local traffic and travel times are expected to provide some lowering of stress and anxiety in the community.

Overall, where project related impacts are mitigated, the potential for significant health impacts from changes in stress and anxiety are considered low.

Section 10. Assessment of cumulative impacts

10.1 General

Cumulative impacts have the potential to occur when benefits or impacts from a project overlap or interact with those of other projects, potentially resulting in a larger overall effect (positive or negative) on the environment or local communities. Cumulative impacts may occur when projects are constructed or operated concurrently or consecutively. Once the project is operational, other projects which interrelate may enhance the project and create positive cumulative benefits.

Four projects were reviewed against the following screening criteria for this cumulative impact assessment:

- spatially relevant (i.e., the development or activity overlaps with, is adjacent to or within two kilometres of the project)
- timing (i.e., the expected timing of its construction and/or operation overlaps or occurs consecutively to construction and/or operation of the project)
- scale (i.e., large-scale major development or infrastructure projects that have the potential to result in cumulative impacts with the project, as listed on the NSW Government Major Project website and on the relevant council websites)
- status (i.e., projects in development with sufficient publicly available information to inform this environmental impact statement and with an adequate level of detail to assess the potential cumulative impacts).

Projects identified as contributing to potential cumulative impacts have met these criteria and include:

- Katoomba to Blackheath Upgrade (including Medlow Bath Upgrade)
- Little Hartley to Lithgow Upgrade.

Given the regional setting of the project primarily within the Blue Mountains Local Government Area (LGA) and a small portion within the Lithgow LGA, there are fewer major projects within the locality.

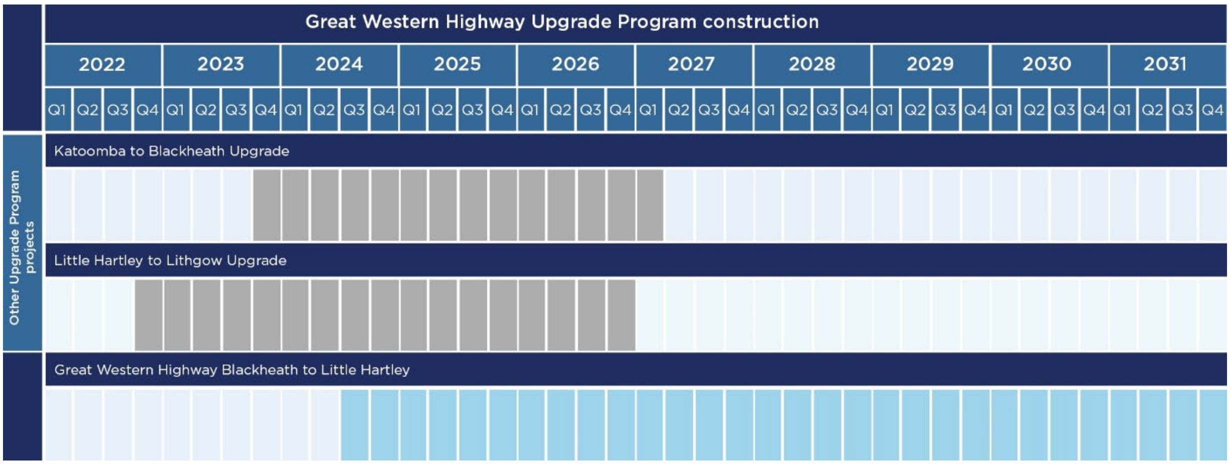


Figure 1-8 shows the interface of the Katoomba to Blackheath Upgrade (including Medlow Bath) and the Little Hartley to Lithgow Upgrade with the project. Chapter 24 (Cumulative impacts) of the EIS details the full cumulative impact assessment methodology adopted for the project.

10.2 Construction

Where construction activities for all projects have the potential to occur at the same time, at or close to the same location, there is the potential for impacts on noise and air quality (dust) to be increased as a result of the increased level of activity. All projects would be required to implement mitigation measures to minimise noise and dust impacts. Where all projects implement such measures the potential for cumulative impacts to be sufficiently elevated to impact on health is considered low (for air quality) to moderate (for noise).

Where construction activities occur consecutively, there is the potential for the duration of construction related impacts to be longer than considered in this assessment. It is expected that project related mitigation measures would adequately address construction related impacts on air quality (dust) and noise such that the levels were not of concern to community health. However extended exposure to construction related impacts may increase levels of stress and anxiety in some individuals located close to the works.

10.3 Operations

The operation of the combined projects allows for the improved flow of traffic into and out of the tunnel. Hence once the project is completed, the cumulative impacts are expected to result in greater community health benefits, with the project providing reduced levels of traffic congestion, reduced travel times and improved air quality and noise adjacent to the Great Western Highway.

Section 11. Uncertainties

11.1 General

Any assessment of health risk or health impact incorporates data and information that is associated with some level of uncertainty. In most cases, where there is uncertainty in any of the key data or inputs into an assessment of health risk or health impact, a conservative approach is adopted. This approach is adopted to ensure that the assessment presents an overestimation of potential health impacts, rather than an underestimation. It is therefore important to provide some additional information on the key areas of uncertainty for the health impact assessment to support the conclusions presented.

11.2 Population health data

There are limitations in the use of this data for the quantification of impact and risk. This data is derived from statistics recorded by hospitals and doctors, reported by postcode of residence, and are dependent on the correct categorisation of health problems upon presentation at the hospital. There may be some individuals who may not seek medical assistance particularly with less serious conditions and hence there is expected to be some level of under-reporting of effects commonly considered in relation to morbidity. Quantitatively, the baseline data considered in this assessment is only a general indicator (not a precise measure) of the incidence of these health endpoints.

11.3 Exposure concentrations

The concentration of various pollutants in air (i.e., exposure concentrations) and noise levels relevant to different locations in the community have been calculated on the basis of a range of input assumptions and modelling. Details of these are presented within the relevant technical appendices to the EIS.

11.4 Approach to the assessment of risk for particulates and NO_2

The available scientific information provides a sufficient basis for determining that exposure to particulate matter (particularly $PM_{2.5}$ and smaller) and NO_2 is associated with adverse health effects in a population. The data is insufficient to provide a thorough understanding of all of the potential toxic properties of particulates to which humans may be exposed. Over time it is expected that many of the current uncertainties would be refined with the collection of additional data, however some uncertainty would be inherent in any estimate. The influence of the uncertainties may be either positive or negative.

Overall, the epidemiological and toxicological data on which the assessment presented in this assessment are based on current and robust information for the assessment of risks to human health associated with the potential exposure to particulate matter and NO_2 from combustion sources.

11.5 Assessment of diesel particulate matter

The assessment of exposure to diesel particulate matter has assumed that 100 per cent of the $PM_{2.5}$ associated with the project is derived from diesel sources. This is a conservative assumption.

The health hazard conclusions associated with exposure to diesel particulate matter are based on studies that are dominated by exhaust emissions from diesel engines built prior to the mid-1990s.

With current engine use including some new and many older engines (engines typically stay in service for a long time), the health hazard conclusions, in general, are likely to be applicable to engines currently in use.

However as new and cleaner diesel engines, together with different diesel fuels, replace a substantial number of existing engines; the general applicability of the health hazard conclusions may require further evaluation. The NEPC (NEPC 2009) has established a program to reduce diesel emissions from the Australian heavy vehicle fleet. This is expected to lower the potential for all diesel emissions over time.

11.6 Co-pollutants

For the assessment of NO_2, particulates and noise, the exposure-response relationships used in this assessment are based on large epidemiology studies where exposures have occurred in urban areas. These exposures do not relate to only one pollutant or exposure (noise) but a mix of these, and others including occupational and smoking. While many of the studies have endeavoured to correct for other pollutants and exposures, no study can fully correct for these and there would always be some level of influence from other exposures on the relationships adopted.

In relation to air quality, many of the pollutants evaluated come from a common source (e.g., fuel combustion) so the use of only particulate matter (or NO_2) as an index for the mix of pollutants that is in urban air at the time of exposure is reasonable but conservative.

In relation to the assessment of cardiovascular effects from road traffic noise, these effects are also associated with (and occur together with) increased exposures to vehicle emissions, specifically particulate exposures.

For this reason, it is important the health risks and incidence evaluations presented for exposure to NO_2, particulates and noise should not be added together as these effects are not necessarily additive as the relationships already include co-exposures to all these aspects (and others).

11.7 Selected health outcomes

The assessment of risk has utilised exposure-response functions and relative risk values that relate to the more significant health endpoints where the most significant and robust positive associations have been identified. The approach does not include all possible subsets of effects that have been considered in various published studies. However, the assessment carried out has considered the health endpoints/outcomes that incorporate many of the subsets, and has utilised the most current and robust relationships.

11.8 Exposure time/duration and peak exposures

The assessment of potential exposure and risk to changes in air quality and noise levels associated with the project has assumed that all areas evaluated are residential and people may be at home for 24 hours of the day for 365 days of the year, for a lifetime. This is a conservative assumption to ensure that all members of the public are adequately addressed in the assessment of health impacts, including the elderly and those with disabilities who may not leave the home very often. As a result, the quantification of risk and health incidence is expected to be an overestimation.

Consideration of peak traffic emissions that may occur during maximum traffic volumes or under the regulatory worst-case scenario would only occur on a limited number of days per year, or not at all (as may be the case for the regulatory worst-case scenario). Risks to community health in relation to long-term exposure to changes in nitrogen dioxide and particulate concentrations as a result of the project do not significantly change from the risks presented in this assessment. This is because the increased level of exposure related to the maximum traffic scenario is small and would not change annual average exposure concentrations or long-term risks.

11.9 Changing population size and demographics

The assessment presented has utilised information on the size of the population and distribution of the population in relevant ages from the ABS Census data from 2021. Some population increase is expected by 2041[10] in the Blue Mountains LGA (0.28% increase per year) with no increase expected for the Lithgow LGA. The LGAs are expecting an increase in the proportion of the population aged 65 years and over.

The change in distribution does not affect the calculation of an individual risk. The key aspect that does affect this calculation is the baseline incidence of the health effects within the population. Based on statistics from NSW Health the baseline incidence of the health effects evaluated in this assessment have been relatively stable or decreasing over time (with improvements in health care). Hence changes in the population over time are not expected to result in any increase in the calculated individual risk.

It is noted that population growth (in the project area as well as the broader population likely to be utilising the road) has been included in the forecast of traffic volumes predicted for the project and hence these changes have, by default, be incorporated into all subsequent impact assessment, including assessments associated with changes in air quality, noise and vibration.

11.10 Application of exposure-response functions to small populations

The exposure-response functions have been developed on the basis of epidemiological studies from large urban populations where associations have been determined between health effects (health endpoints) and changes in ambient (regional) particulate levels. Typically, these exposure-response functions are applied to large populations for the purpose of establishing/reviewing air guidelines or reviewing potential impacts of regional air quality issues on large populations. When applied to small populations (less than larger urban centres such as the whole of Greater Sydney) the uncertainty increases.

In addition, it is noted that the exposure-response functions relate changes in health endpoints with changes in regional air quality measurements. They do not relate to specific local sources (which occur within a regional airshed), or daily variability in exposure that may occur as a result of various different activities that may occur in any one day.

11.11 Overall evaluation of uncertainty

Overall, the assessment of potential health impacts presented in this report has incorporated a range of assumptions and models that will have resulted in an overestimation of impacts, including

[10] https://pp.planningportal.nsw.gov.au/populations

the use of traffic demand models. The most significant factors that result in the assessment providing conservative outcomes are as follows:

- modelling of potential air quality impacts – this has included a range of conservative assumptions about the type of vehicles and the emissions to air that may come from these vehicles over time. The assessment has also utilised a model to predict ground level concentrations (i.e., concentrations in the community) that are expected to be conservative. The modelling provides an indication of the likely level of pollutants in the community, however the model predictions are typically conservative and tend to overpredict maximum pollutant concentrations in the community
- potential community exposures – there are a number of assumptions adopted in the characterisation of exposure that will have overestimated exposure:
    - it is assumed that the maximum changes in air quality for all receptors relates to a residential building, not a premises used for commercial purposes
    - all exposures to changes in air quality and noise that occur, in all areas, assume that all residents are at home all day, every day for a lifetime.
- potential exposure-response – the relationships utilised in this assessment are based on the most current, robust studies that are relate to health effects from exposure to changes in nitrogen dioxide and particulates. The relationships adopted come from large epidemiology studies that include a number of co-pollutants (i.e., exposure occurs to a wide range of factors not just the pollutant being evaluated) and confounding factors that can result in more conservative relationships being developed. In addition, it is assumed the relationships adopted are linear and apply to small changes in air quality, at levels that would not be measurable with air monitoring equipment.

Section 12. Summary and conclusions

This section summarises the health impacts and benefits identified in relation to the project. **Table 12-2** summarises the health impacts and benefits for the overall project.

Performance outcomes have been developed that are consistent with the SEARs for the project. The performance outcomes for the project are summarised below in **Table 12-1** and identify measurable, performance-based standards for environmental management.

Table 12-1 Performance outcomes for the project - Human health

Desired performance outcome	Project performance outcome	Timing
7. Health and Safety		
The project avoids or minimises any adverse health impacts arising from the project. The project avoids, to the greatest extent possible, risk to public safety	The project will be designed to minimise and avoid adverse impacts to human health and avoid risks to public safety.	Construction and operation

Table 12-2: Summary of human health impact assessment

Health aspect/ issue	Health impacts identified	Health benefits identified
Air quality		
Construction	Potential impacts are considered to be low. The implementation of dust mitigation would further reduce potential exposures during construction works.	None
Operations	The project would result in some redistribution of traffic on surface roads, which would redistribute air emissions. Localised health impacts from the project, for both ventilation options, and the redistribution of surface road traffic are considered to be low and acceptable and not measurable within the community. It is noted that the maximum localised/individual risk associated with exposure to particulate emissions is lower where the project design includes ventilation outlets.	The redistribution of traffic on surface roads would result in an overall improvement in air quality in the community, for both ventilation options (portals and ventilation outlets).
In-tunnel exposures	In-tunnel air guidelines for carbon monoxide and nitrogen dioxide would be adequately protective of the health of tunnel users. Short-duration exposures to higher levels of particulates should be minimised by providing advice to motorists to keep windows closed and switch vehicle ventilation to recirculation.	None
Vibration		
Construction	Where there is the potential for construction works to occur at locations where impacts on human comfort may occur, mitigation measures, including notification requirements would be implemented. Where such measures are implemented, no impacts on human health are expected within the community.	None
Operation	No operational vibration impacts identified.	None
Noise		
Construction	Noise impacts have been identified during construction works, which would require the implementation of mitigation measures. Where these measures are implemented the potential for noise impacts to result in significant health impacts in the community is low to moderate, depending on the	None

Health aspect/ issue	Health impacts identified	Health benefits identified
	mitigation measures implemented. Effective communication of noisy activities is important in managing such impacts on the community. However, it is expected that some individuals within the community may find construction noise annoying at times, even with mitigation. The management of noise impacts during construction would include a notification and complaints system.	
Operation	There are some localised areas where an increase in noise has been predicted, particularly where there are increases in surface road traffic or close to the tunnel portals (from the operation of jet fans). Additional noise mitigation has been identified to minimise the impact of changes in project-related noise. Where these additional noise mitigation measures are implemented, changes in noise levels associated with the project are not expected to result in health impacts within the community that would be measurable.	There would be a reduction in road noise at a substantial number of sensitive receptors where the tunnel provides a bypass to the existing surface road. This reduction in noise would provide some health benefit.
Safety and contamination		
Safety	The potential for project related activities to pose a risk to public safety is considered low to moderate. During construction mitigation measures would adequately address the moderate risks identified. During operation additional assessment would be required to adequately manage risks related to coal seam gas (methane).	The project (and associated projects) is expected to reduce crashes and improve pedestrian and cyclist safety through upgrades to the road and active transport network.
Contamination	The potential for contamination (soil, water or surface water) to pose a risk to the community is considered to be low during construction and operation. It is noted that management measures have been identified to minimise the potential for contamination to impact on the community. No health impacts would be associated with the management of these materials.	
Other aspects		
Economic	None identified	Construction of the project would provide the opportunity for increased employment. Once the project was complete, a number of substantial economic benefits would be generated for the local area. In addition, a range of benefits have been identified for businesses in the region with productivity and efficiency gains, improved access and improved transport links. Increased employment has a range of significant health benefits.
Traffic	Some increase in traffic congestion during construction may increase stress and anxiety levels.	Once constructed, reduced travel times would result in lower levels of stress and the potential for additional time to be used for social or physical exercise.
Public transport	Existing public transport routes would be maintained during construction and operation of the project. Any impacts to existing bus routes during construction are considered to be minimal.	None identified.
Pedestrian and cyclist access	The project would not change existing pedestrian and cycle access.	Benefits relating to pedestrian and cycle access relate to the completion of the project and associated projects (Katoomba to Blackheath Upgrade and Little Hartley to Lithgow Upgrade projects)

Health aspect/ issue	Health impacts identified	Health benefits identified
Health and emergency services	There would be no changes to the access or availability of these services as a result of the project.	NA
Visual	The project would result in some changes to the landscape character and visual aspects of the local areas around Blackheath and Little Hartley. These impacts are considered higher where ventilation outlets are constructed. Any impacts relating to these changes are expected to be managed and would not impact on health, however there may be some individuals where these changes result in an increase in stress and anxiety.	None identified
Property acquisition	There would be minimal impact on the community as the project involves the acquisition of one property and the temporary use of one other property. Impacts on specific individuals involved in the acquisitions would be managed. Impacts on the broader community are considered low.	None identified
Green space	There would be no material changes to the availability, access and use of green space, passive and active recreation areas as a result of the project.	None identified
Equity	No impacts have been identified with potential to be unfairly or unequally distributed within the community.	None identified

Based on the above the following can be concluded:

Construction

Where appropriate management mitigation measures are implemented to manage dust emissions, noise and vibration during construction, residual risks to human health are considered low. It is expected there may be some disruptions to local traffic, pedestrian and cyclist access during construction.

Operation

Changes in air quality (impacts) due to emissions from the project for both tunnel ventilation options as well as the redistribution of traffic on surface roads within the broader study area (community) indicate some improvement in air quality and health.

There would be some localised changes associated with the redistribution of traffic on surface roads that would improve air quality, and the potential for some health benefits. Some other localised areas would experience impacts (or decreased air quality) at locations closer to the portals and ventilation outlets. These impacts are not considered to be associated with significant or measurable impacts on community health.

Changes in noise due to the project are expected to reduce overall noise impacts from road traffic, potentially resulting in some health benefits. Where localised changes in noise are considered (including localised areas of increased noise), and where proposed noise mitigation measures are considered (including at-property treatments) there would be no significant health impacts.

A range of other changes are associated with the project, including faster travel times, more employment opportunities and jobs growth, and improvements in transport networks. These all have potential to generate health benefits within the community. However, some changes may increase stress and anxiety levels. Where these impacts are managed appropriately there would be no significant impacts to community health.

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Annexure A: Approach to risk assessment using exposure-response relationships

A1 Mortality and morbidity health endpoints

A quantitative assessment of risk for these endpoints uses a mathematical relationship between an exposure concentration (i.e., concentration in air) and a response (namely a health effect). This relationship is termed an exposure-response relationship and is relevant to the range of health effects (or endpoints) identified as relevant (to the nature of the emissions assessed) and robust (as identified in the main document). An exposure-response relationship can have a threshold, where there is a safe level of exposure, below which there are no adverse effects; or the relationship can have no threshold (and is regarded as linear) where there is some potential for adverse effects at any level of exposure.

In relation to the health effects associated with exposure to nitrogen dioxide and particulate matter, no threshold has been identified. Non-threshold exposure-response relationships have been identified for the health endpoints considered in this assessment.

The assessment of potential risks associated with exposure to particulate matter involves the calculation of a relative risk (RR). For the purpose of this assessment the shape of the exposure-response function used to calculate the relative risk is assumed to be linear[11]. The calculation of a relative risk based on the change in relative risk exposure concentration from baseline/existing (ie based on incremental impacts from the project) can be calculated on the basis of the following equation (Ostro 2004):

Equation 1 **RR = exp[β(X-X0)]**

Where:
X-X0 = the change in particulate matter concentration to which the population is exposed (µg/m³)
β = regression/slope coefficient, or the slope of the exposure-response function which can also be expressed as the per cent change in response per 1 µg/m³ increase in particulate matter exposure.

Based on this equation, where the published studies have derived relative risk values that are associated with a 10 micrograms per cubic metre increase in exposure, the β coefficient can be calculated using the following equation:

Equation 2

$$\beta = \frac{\ln(RR)}{10}$$

11 Some reviews have identified that a log-linear exposure-response function may be more relevant for some of the health endpoints considered in this assessment. Review of outcomes where a log-linear exposure-response function has been adopted (Ostro 2004) for $PM_{2.5}$ identified that the log-linear relationship calculated slightly higher relative risks compared with the linear relationship within the range 10–30 micrograms per cubic metre,(relevant for evaluating potential impacts associated with air quality goals or guidelines) but lower relative risks below and above this range. For this assessment (where impacts from a particular project are being evaluated) the impacts assessed relate to concentrations of $PM_{2.5}$ that are well below 10 micrograms per cubic metre and hence use of the linear relationship is expected to provide a more conservative estimate of relative risk.

Where:
RR = relative risk for the relevant health endpoint as published (µg/m³)
10 = increase in particulate matter concentration associated with the RR (where the RR is associated with a 10 µg/m³ increase in concentration).

A2 Quantification of impact and risk

The assessment of health impacts for a particular population associated with exposure to particulate matter has been carried out utilising the methodology presented by the WHO (Ostro 2004)[12] where the exposure-response relationships identified have been directly considered on the basis of the approach outlined below.

The calculation of changes in health endpoints associated with exposure to nitrogen dioxide and particulate matter as outlined by the WHO (Ostro 2004) has considered the following four elements:

- estimates of the changes in particulate matter exposure levels (ie incremental impacts) due to the project for the relevant modelled scenarios
- estimates of the number of people exposed to particulate matter at a given location
- baseline incidence of the key health endpoints that are relevant to the population exposed
- exposure-response relationships expressed as a percentage change in health endpoint per microgram per cubic metre change in NO_2 or particulate matter exposure, where a relative risk (RR) is determined (refer to Equation 1).

From the above, the increased incidence of a health endpoint corresponding to a particular change in particulate matter concentrations can be calculated using the following approach:

The attributable fraction/portion (AF) of health effects from air pollution, or impact factor, can be calculated from the relative risk (calculated for the incremental change in concentration considered as per Equation 1) as:

Equation 3 $AF = \frac{RR-1}{RR}$

The total number of cases attributable to exposure to particulate matter (where a linear dose-response is assumed) can be calculated as:

12 For regional guidance, such as that provided for Europe by the WHO WHO 2006b, Health risks or particulate matter from long-range transboundary air pollution regional background incidence data for relevant health endpoints are combined with exposure-response functions to present an impact function, which is expressed as the number/change in incidence/new cases per 100,000 population exposed per microgram per cubic metre change in particulate matter exposure. These impact functions are simpler to use than the approach adopted in this assessment, however in utilising this approach it is assumed that the baseline incidence of the health effects is consistent throughout the whole population (as used in the studies) and is specifically applicable to the sub-population group being evaluated. For the assessment of exposures in the areas evaluated surrounding the project it is more relevant to utilise local data in relation to baseline incidence rather than assume that the population is similar to that in Europe (where these relationships are derived).

Equation 4 $E = AF \times B \times P$

Where:
B = baseline incidence of a given health effect (eg mortality rate per person per year)
P = relevant exposed population

The above approach (while presented slightly differently) is consistent with that presented in Australia (Burgers & Walsh 2002), US (OEHHA 2002; USEPA 2005b, 2010) and Europe (Martuzzi et al. 2002; Sjoberg et al. 2009).

The calculation of an increased incidence (ie number of cases) of a particular health endpoint is not relevant to a specific individual, rather this is relevant to a statistically relevant population. This calculation has been carried out for populations within the suburbs surrounding the proposed project. When considering the potential impact of the project on the population, the calculation has been carried out using the following:

- Equation 1 has been used to calculate a relative risk. The relative risk has been calculated for a population weighted annual average incremental increase in concentrations. The population weighted average has been calculated on the basis of the smallest statistical division provided by the Australian Bureau of Statistics within a suburb (ie mesh blocks – which are small blocks that cover an area of about 30 urban residences). For each mesh block in a suburb the average incremental increase in concentration has been calculated and multiplied by the population living in the mesh block (data available from the ABS for the 2011 census year). The weighted average has been calculated by summing these calculations for each mesh block in a suburb and dividing by the total population in the suburb (ie in all the mesh block)
- Equation 3 has been used to calculate an attributable fraction
- Equation 4 has been used to calculate the increased number of cases associated with the incremental impact evaluated. The calculation is carried out utilising the baseline incidence data relevant for the endpoint considered and the population (for the relevant age groups) present in the suburb.

The above approach can be simplified (mathematically, where the incremental change in particulate concentration is low, less than one microgram per cubic metre) as follows:

Equation 5 $E = \beta \times B \times \sum_{mesh} (\Delta X_{mesh} \times P_{mesh})$

Where:
β = slope coefficient relevant to the per cent change in response to a 1 µg/m³ change in exposure concentration
B = baseline incidence of a given health effect per person (eg annual mortality rate)
ΔX_{mesh} = change (increment) in exposure concentration in µg/m³ as an average within a small area defined as a mesh block (from the ABS – where many mesh blocks make up a suburb)
P_{mesh} = population (residential – based on data from the ABS) within each small mesh block

An additional risk can then be calculated as:

Equation 6 **Risk=β x ∆X x B**

$$Risk = \beta \times \Delta X \times B$$

Where:
β = slope coefficient relevant to the per cent change in response to a 1 μg/m³ change in exposure
ΔX = change (increment) in exposure concentration in μg/m³ relevant to the project at the point of exposure
B = baseline incidence of a given health effect per person (eg annual mortality rate)

This calculation provides an annual risk for individuals exposed to changes in air quality from the project at specific locations (such as the maximum, or at specific sensitive receptor locations). The calculated risk does not take into account the duration of exposure at any one location and hence is considered to be representative of a population risk.

A3 Quantification of short and long term effects

The concentration-response functions adopted for the assessment of exposure are derived from long and short term studies and relate to short or long term effects endpoints (eg change in incidence from daily changes in nitrogen dioxide or particulate matter, or chronic incidence from long term exposures to particulate matter).

Long term or chronic effects are assessed on the basis of the identified exposure-response function and annual average concentrations. These then allow the calculation of a chronic incidence of the assessed health endpoint.

Short term effects are also assessed on the basis of an exposure-response function that is expressed as a percentage change in endpoint per microgram per cubic metre change in concentration. For short term effects, the calculations relate to daily changes in nitrogen dioxide and particulate matter exposures to calculate changes in daily effects endpoints. While it may be possible to measure daily incidence of the evaluated health endpoints in a large population study specifically designed to include such data, it is not common to collect such data in hospitals nor are effects measurable in smaller communities. Instead these calculations relate to a parameter that is measurable, such as annual incidence of hospitalisations, mortality or lung cancer risks. The calculation of an annual incidence or additional risk can be carried out using two approaches (Ostro 2004; USEPA 2010):

- calculate the daily incidence or risk at each receptor location over every 24 hour period of the year (based on the modelled incremental 24 hour average concentration for each day of the year and daily baseline incidence data) and then sum the daily incidence/risk to get the annual risk
- calculate the annual incidence/risk based on the incremental annual average concentration at each receptor (and using annual baseline incidence data).

In the absence of a threshold, and assuming a linear concentration-response function (as is the case in this assessment), these two approaches result in the same outcome mathematically (calculated incidence or risk). Given that it is much simpler computationally to calculate the incidence (for each receptor) based on the incremental annual average, compared with calculating effects on each day of the year and then summing, this is the preferred calculation method. It is the recommended method outlined by the WHO (Ostro 2004).

The use of the simpler approach, based on annual average concentrations should not be taken as implying or suggesting that the calculation is quantifying the effects of long term exposure.

Hence for the calculations presented in this technical working paper that relate to the expected use of the project tunnel, for both long term and short term effects, annual average concentrations of nitrogen dioxide and particulate matter have been utilised.

Where short term worst case exposures are assessed (such as those related to a breakdown in the tunnel) short term, daily, calculations have been carried out to assessed short term health endpoints. This has been carried out as the exposure being assessed relates to an infrequent short duration event. It would not occur each day of the year and hence it is not appropriate to assess on the basis of an annual average.

Annexure B: Approach to assessment of cancer risk

Diesel exhaust (DE) is emitted from ‘on-road’ diesel engines (vehicle engines) and can be formed from the gaseous compounds emitted by diesel engines (secondary particulate matter). After emission from the exhaust pipe, diesel exhaust undergoes dilution and chemical and physical transformations in the atmosphere, as well as dispersion and transport in the atmosphere. The atmospheric lifetime for some compounds present in diesel exhaust ranges from hours to days.

Data from the USEPA (USEPA 2002b) indicates that diesel exhaust as measured as diesel particulate matter made up about six per cent of the total ambient/urban air $PM_{2.5}$. In this project, emissions to air from the operation of the tunnel include a significant proportion of diesel powered vehicles. Available evidence indicates that there are human health hazards associated with exposure to diesel particulate matter. The hazards include acute exposure-related symptoms, chronic exposure related non-cancer respiratory effects, and lung cancer.

In relation to non-carcinogenic effects, acute or short term (eg episodic) exposure to diesel particulate matter can cause acute irritation (eg eye, throat, bronchial), neurophysiological symptoms (eg light-headedness, nausea), and respiratory symptoms (cough, phlegm). There also is evidence for an immunologic effect-exacerbation of allergenic responses to known allergens and asthma-like symptoms. Chronic effects include respiratory effects. The review of these effects (USEPA 2002b) identified a threshold concentration for the assessment of chronic non-carcinogenic effects. The review conducted by the USEPA also concluded that exposures to diesel particulate matter also consider $PM_{2.5}$ goals (as these also address the presence of diesel particulate matter in urban air environments). The review found that the diesel particulate matter chronic guideline would also be met if the $PM_{2.5}$ guideline was met.

Review of exposures to diesel particulate matter (USEPA 2002b) identified that such exposures are ‘likely to be carcinogenic to humans by inhalation’. A more recent review by IARC (Attfield et al. 2012; IARC 2012; Silverman et al. 2012) classified diesel engine exhaust as carcinogenic to humans (Group 1) based on sufficient evidence that exposure is associated with an increased risk for lung cancer. In addition, outdoor air pollution and particulate matter (that includes diesel particulate matter) have been classified by IARC as carcinogenic to humans based on sufficient evidence of lung cancer.

Many of the organic compounds present in diesel exhaust are known to have mutagenic and carcinogenic properties and hence it is appropriate that a non-threshold approach is considered for the quantification of lung-cancer endpoints.

In relation to quantifying carcinogenic risks associated with exposure to diesel exhaust, the USEPA (USEPA 2002b) has not established a non-threshold value (due to uncertainties identified in the available data).

WHO has used data from studies in rats to estimate unit risk values for cancer (WHO 1996). Using four different studies where lung cancer was the cancer endpoint, WHO calculated a range of 1.6×10^{-5} to 7.1×10^{-5} per microgram per cubic metres (mean value of 3.4×10^{-5} per microgram per cubic metres). This would suggest that an increase in lifetime exposure to diesel particulate matter between 0.14 and 0.625 microgram per cubic metres could result in a one in one hundred thousand excess risk of cancer.

The California Environmental Protection Agency has proposed a unit lifetime cancer risk of 3.0×10^{-4} per microgram per cubic metres diesel particulate matter (OEHHA 1998). This was derived from data on exposed workers and based on evidence that suggested unit risks between

1.5 x 10^{-4} and 15 x 10^{-4} per microgram per cubic metres. This would suggest that an increase in lifetime exposure to diesel particulate matter of 0.033 microgram per cubic metres could result in a one in one hundred thousand excess risk of cancer. This estimate has been widely criticised as overestimating the risk and hence has not been considered in this assessment.

On the basis of the above, the WHO cancer unit risk value (mean value of 3.4 x 10^{-5} per microgram per cubic metres) has been used to evaluate potential excess lifetime risks associated with incremental impacts from diesel particulate matter exposures. Diesel particulate matter has not been specifically modelled in the Technical working paper: Air quality (ERM, 2018); rather diesel particulate matter is part of the $PM_{2.5}$ assessment. For the purpose of this assessment it has been conservatively assumed that 100 per cent of the incremental $PM_{2.5}$ (from the project only) is derived from diesel sources. This is conservative as not all the vehicles using the tunnel (and emitting $PM_{2.5}$) would be diesel powered (as currently there is a mix of petrol, diesel, LPG and hybrid-electric powered vehicles with the proportion of alternative fuels rising in the future).

For the assessment of potential lung cancer risks associated with exposure to diesel particulate matter, a non-threshold cancer risk is calculated. Non-threshold carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential non-threshold carcinogen. The numerical estimate of excess lifetime cancer risk is calculated as follows for inhalation exposures (USEPA 2009b):

Equation 7 Carcinogenic Risk (inhalation) = Concentration in Air x Inhalation Unit Risk x AF

Exposure adjustment factor (AF):

The above calculation assumes the receptor is exposed at the same location for 24 hours of the day, every day, for a lifetime (which is assumed to be 70 years). This assumption is overly conservative for residents and workers in the community surrounding the project. Residents do not live in the one home for a lifetime. Guidance from enHealth indicates that an appropriate assumption for the time living in the one home is 35 years (enHealth 2012b). For residents, it is assumed that they may be at home for 20 hours per day for 365 days of the year, for 35 years. This results in an adjustment factor of 0.4 (20/24 hours x 35 years/70 years). This factor has been adopted for the assessment of all exposures regardless of whether these are residential areas, schools, recreational areas or workplaces.

Annexure C: Acceptable risk levels

C1 General

The acceptability of an additional population risk is the subject of some discussion as there are currently no guidelines available in Australia, or internationally, in relation to an acceptable level of population risk associated with exposure to particulate matter. More specifically there are no guidelines available that relate to an acceptable level of risk for a small population (associated with impacts from a specific activity or project) compared with risks that are relevant to whole urban populations (that are considered when deriving guidelines). The following provides additional discussion in relation to evaluating calculated risk levels.

> *'The solution to developing better criteria for environmental contaminants is not to adopt arbitrary thresholds of 'acceptable risk' in an attempt to manage the public's perception of risk, or develop oversimplified tools for enforcement or risk assessment. Rather, the solution is to standardize the process by which risks are assessed, and to undertake efforts to narrow the gap between the public's understanding of actual vs. perceived risk. A more educated public with regard to the actual sources of known risks to health, environmental or otherwise, will greatly facilitate the regulatory agencies' ability to prioritize their efforts and standards to reduce overall risks to public health.'* (Kelly 1991).

Most human activities that have contributed to economic progress present also some disadvantages, including risks of different kinds that adversely affect human health. These risks include air or water pollution due to industrial activities (coal power generation, chemical plants, and transportation), food contaminants (pesticide residues, additives), and soil contamination (hazardous waste). Despite all possible efforts to reduce these threats, it is clear that the zero risk objective is unobtainable or simply not necessary for human and environmental protection and that a certain level of risk in a given situation is deemed 'acceptable' as the effects are so small as to be negligible or undetectable. Risk managers need to cope with some residual risks and thus must adopt some measure of an acceptable risk.

Much has been written about how to determine the acceptability of risk. The general consensus in the literature is that 'acceptability' of a risk is a judgment decision properly made by those exposed to the hazard or their designated health officials. It is not a scientifically derived value or a decision made by outsiders to the process. Acceptability is based on many factors, such as the number of people exposed, the consequences of the risk, the degree of control over exposure, and many other factors.

The USEPA (Hoffman 1988) 'surveyed a range of health risks that our society faces' and reviewed acceptable-risk standards of government and independent institutions. The survey found that 'No fixed level of risk could be identified as acceptable in all cases and under all regulatory programs...,' and that: '...the acceptability of risk is a relative concept and involves consideration of different factors'. Considerations may include:

- the certainty and severity of the risk
- the reversibility of the health effect
- the knowledge or familiarity of the risk
- whether the risk is voluntarily accepted or involuntarily imposed
- whether individuals are compensated for their exposure to the risk
- the advantages of the activity
- the risks and advantages for any alternatives.

To regulate a technology in a logically defensible way, one must consider all its consequences, ie both risks and benefits.

C2 10^{-6} as an 'acceptable' risk level?

The concept of $1x10^{-6}$ (10^{-6}) was originally an arbitrary number, finalised by the US Food and Drug Administration (FDA) in 1977 as a screening level of 'essentially zero' or de minimus risk. The term de minimus is an abbreviation of the legal concept, 'de minimus non curat lex: the law does not concern itself with trifles.' In other words, 10^{-6} was developed as a level of risk below which risk was considered a 'trifle' and not of concern in a legal case.

This concept was traced back to a 1961 proposal by two scientists from the National Cancer Institute regarding methods to determine 'safety' levels in carcinogenicity testing. The FDA applied the concept in risk assessment in its efforts to deal with diethylstilboestrol as a growth promoter in cattle. The threshold of one in a million risk of developing cancer was established as a screening level to determine what carcinogenic animal drug residues merited further regulatory consideration. In the FDA legislation, the regulators specifically stated that this level of 'essentially zero' was not to be interpreted as equal to an acceptable level of residues in meat products. Since then, the use of risk assessment and 10^{-6} (or variations thereof) have been greatly expanded to almost all areas of chemical regulation, to the point where today one-in-a-million (10^{-6}) risk means different things to different regulatory agencies in different countries. What the FDA intended to be a lower regulatory level of 'zero risk' below which no consideration would be given as to risk to human health, for many regulators it somehow came to be considered a maximum or target level of 'acceptable' risk (Kelly 1991).

When evaluating human health risks, the quantification of risk can involve the calculation of an increased lifetime chance of cancer (as is calculated for diesel particulate matter in this assessment) or an increased probability of some adverse health effect (or disease) occurring, over and above the baseline incidence of that health effect/disease in the community (as is calculated for exposure to particulate matter).

In the context of human health risks, 10^{-6} is a shorthand description for an increased chance of 0.000001 in one (one chance in a million) of developing a specific adverse health effect due to exposure (over a lifetime or a shorter duration as relevant for particulate matter) to a substance. The number 10^{-5} represents one chance in 100,000, and so on.

Where cancer may be considered, lifetime exposure to a substance associated with a cancer risk of $1x10^{-6}$ would increase an individual's current chances of developing cancer from all causes (which is 40 per cent, or 0.4 – the background incidence of cancer in a lifetime) from 0.4 to 0.400001, an increase of 0.00025 per cent.

For other health indicators considered in this assessment, such as cardiovascular hospitalisations for people aged 65 years and older (for example), an increased risk of 10^{-6} (one chance in a million) would increase an individual's (aged 65 years and older) chance of hospitalisation for cardiovascular disease (above the baseline incidence of 23 per cent, or 0.23) from 0.23 to 0.230001, an increase of 0.00043 per cent.

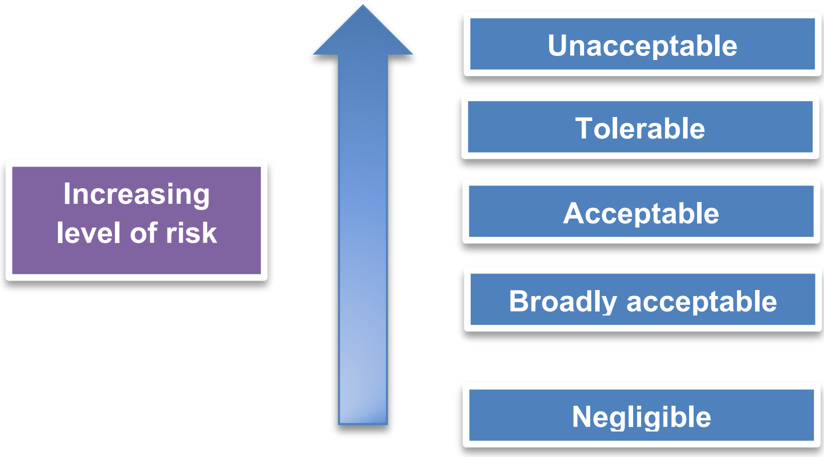
To provide more context in relation to the concept of a one in a million risk, the following presents a range of everyday life occurrences. The activity and the time spent undertaking the activity that is associated with reaching a risk of one in a million for mortality are listed below (Higson 1989; NSW Planning 2011):

- motor vehicle accident – 2.5 days spent driving a motor vehicle to reach one in a million chance of having an accident that causes mortality (death)
- home accidents – 3.3 days spent within a residence to reach a one in a million chance of having an accident at home that causes mortality
- pedestrian accident (being struck by vehicles) – 10 days spent walking along roads to reach a one in a million chance of being struck by a vehicle that causes mortality
- train accident – 12 days spent travelling on a train to reach a one in a million chance of being involved in an accident that causes mortality
- falling down stairs [1] – 66 days spent requiring the use of stairs in day-to-day activities to reach a one in a million chance of being involved in a fall that causes mortality
- falling objects – 121 days spent in day-to-day activities to reach a one in a million chance of being hit by a falling object that causes mortality.

This risk level should also be considered in the context that everyone has a cumulative risk of death that ultimately must equal one and the annual risk of death for most of one's life is about one in 1000.

While various terms have been applied, it is clear that the two ends of what is a spectrum of risk are the 'negligible' level and the 'unacceptable' level. Risk levels intermediate between these are frequently adopted by regulators with varying terms often used to describe the levels. When considering a risk derived for an environmental impact it is important to consider that the level of risk that may be considered acceptable would lie somewhere between what is negligible and unacceptable, as illustrated below.

[1] Mortality risks as presented by: http://www.riskcomm.com/visualaids/riskscale/datasources.php.



The calculated individual lifetime risk of death or illness due to an exposure to a range of different environmental hazards covers many orders of magnitude, ranging from well less than 10^{-6} to levels of 10^{-3} and higher (in some situations). However, most figures for an acceptable or a tolerable risk range between 10^{-6} to 10^{-4}, used for either one year of exposure or a whole life exposure. It is noteworthy that 10^{-6} as a criterion for 'acceptable risk' has not been applied to all sources of exposure or all agents that pose risk to public health.

A review of the evolution of 10^{-6} reveals that perception of risk is a major determinant of the circumstances under which this criterion is used. The risk level 10^{-6} is not consistently applied to all environmental legislation. Rather, it seems to be applied according to the general perception of the risk associated with the source being regulated and where the risk is being regulated (with different levels selected in different countries for the same sources).

A review of acceptable risk levels at the USEPA (Schoeny 2008) points out that risk assessors can identify risks and possibly calculate their value but cannot determine what is acceptable. Acceptability is a value judgment that varies with type of risk, culture, voluntariness and many other factors. Acceptability may be set by convention or law. The review also states that the USEPA aims for risk levels between 10^{-6} and 10^{-4} for risks calculated to be linear at low dose, while for other endpoints, not thought to be linear at low dose, the risk is compared to Reference Dose/Concentrations or guideline levels. The USEPA typically uses a target reference risk range of 10^{-4} to 10^{-6} for carcinogens in drinking water, which is in line with World Health Organization (WHO) guidelines for drinking water quality which, where practical, base guideline values for genotoxic carcinogens on the upper bound estimate of an excess lifetime cancer risk of 10^{-5}.

There are many different ways to define acceptable risk and each way gives different weight to the views of different stakeholders in the debate. No definition of 'acceptable' would be acceptable to all stakeholders. Resolving such issues, therefore, becomes a political (in the widest sense) rather than a strictly health process.

The following is a list of standpoints that could be used as a basis for determining when a risk is acceptable or, perhaps, tolerable. The WHO (Fewtrell & Bartram 2001) address standards related to water quality. They offer the following guidelines for determining acceptable risk. A risk is acceptable when:

- it falls below an arbitrary defined probability
- it falls below some level that is already tolerated
- it falls below an arbitrary defined attributable fraction of total disease burden in the community
- the cost of reducing the risk would exceed the costs saved
- the cost of reducing the risk would exceed the costs saved when the 'costs of suffering' are also factored in
- the opportunity costs would be better spent on other, more pressing, public health problems
- public health professionals say it is acceptable
- the general public say it is acceptable (or more likely, do not say it is not)
- politicians say it is acceptable.

In everyday life individual risks are rarely considered in isolation. It could be argued that a sensible approach would be to consider health risks in terms of the total disease burden of a community and to define acceptability in terms of it falling below an arbitrary defined level. A problem with this approach is that the current burden of disease attributable to a single factor, such as air pollution, may not be a good indicator of the potential reductions available from improving other environmental health factors. For diseases such as cardiovascular disease where causes are multifactorial, reducing the disease burden by one route may have little impact on the overall burden of disease.

C3 Overall

It is not possible to provide a rigid definition of acceptable risk due to the complex and context driven nature of the challenge. It is possible to propose some general guidelines as to what might be an acceptable risk for specific development projects.

If the level of 10^{-6} (one chance in a million) were retained as a level of increased risk that would be considered as a negligible risk in the community, then the level of risk that could be considered to be tolerable would lie between this level and an upper level that is considered to be unacceptable.

While there is no guidance available on what level of risk is considered to be unacceptable in the community, a level of 10^{-4} for increased risk (one chance in 10,000) has been generally adopted by health authorities as a point where risk is considered to be unacceptable in the development of drinking water guidelines (that impact on whole populations) (for exposure to carcinogens as well as for annual risks of disease (Fewtrell & Bartram 2001)) and in the evaluation of exposures from pollutants in air (NSW DEC 2005).

Between an increased risk level considered negligible (10^{-6}) and unacceptable (10^{-4}) lie risks that may be considered to be tolerable or even acceptable. Tolerable risks are those that can be tolerated (and where the best available, and most appropriate, technology has been implemented to minimise exposure) in order to realise some benefit.

In a societal context, risks are inevitable and any new development would be accompanied by risks which are not amenable or economically feasible to reduce below a certain level. It is not good policy to impose an arbitrary risk level to such developments without consideration of the myriad factors that should be brought into play to determine what is 'tolerable'.

When considering the impacts associated with this project, it is important to note that there are a range of benefits associated with the project and the design of the project has incorporated measures to minimise exposures to traffic-related emissions in the local areas. Hence for this project the calculated risks have been considered to be tolerable when in the range of 10^{-6} and 10^{-4} of increased risk and where the increased incidence of the health impacts are considered to be insignificant.

C4 Determination of significance of population impacts

The assessment of potential health impacts associated with emissions to air from the project has not only calculated an increased annual risk, relevant to the health endpoints considered, but also a change in the incidence, i.e. the additional (or saving of) number of cases, of the adverse effects occurring within the population potentially exposed. The calculated change in incidence need to be considered in terms of what may be significant.

In relation to the calculated change in incidence of an adverse health effect occurring in a population, the following is noted for the primary health indicators (based on statistics available from NSW Health[13]):

- in relation to mortality (all causes), the health statistics available show that for the year 2011/2012 the variability in all admissions data reported (based on the 95 per cent confidence interval for data reported in Sydney) is around ± 2.5 per cent. This is the variability in the data reported in one year. Each year the mortality rate also varies with around one per cent variability reported in the mortality rate (number reported for all causes) between 2010/11 and 2011/12. Based on the population considered in this assessment and the baseline incidence, a one per cent variability results in ± 10 cases per year. Changes in mortality within this range would not be detected (above normal variability) in the health statistics
- in relation to cardiovascular disease hospitalisations, the health statistics available show that for the year 2013/2014 the variability in all admissions data reported (based on the 95 percent confidence interval for data reported in Sydney) is around ± two percent. This is the variability in the data reported in one year. Each year the rate of hospitalisations (all ages) also varies with around two to three per cent variability reported in the number of hospitalisations for people aged 65 years and older in each year between 2010/11 and 2013/14. Based on the baseline incidence of cardiovascular hospitalisations considered in this assessment for individuals aged 65 years and the population considered in this assessment a variability of two per cent equates to ± 40 cases per year. Changes in cardiovascular hospitalisations in the population aged 65 years and older within this range would not be detected (above normal variability) in the health statistics
- in relation to respiratory disease hospitalisations, the health statistics available show that for the year 2013/2014 the variability in all admissions data reported (based on the 95 per cent confidence interval for data reported in Sydney) is around ± six per cent. This is the variability in the data reported in one year. Each year the rate of hospitalisations (all ages)

[13] It is noted that the data presented relates to the period 2011 to 2014, which is considered to provide a representative sample for the purpose of discussion. The same observations can be made with the more recently published health data, which provide the same outcome.

also varies with around three to four per cent variability reported in the number of hospitalisations (all ages) in each year between 2011 and 2014. Based on the baseline incidence of respiratory hospitalisations considered in this assessment for individuals aged 65 years and older, and the population evaluated in this assessment, a variability of three per cent equates to ± 25 cases per year. Changes in respiratory hospitalisations in the population aged 65 years and older within this range would not be detected (above normal variability) in the health statistics.

Where changes in air quality associated with this project are well below 10 cases per year they are considered to be within the normal variability of health statistics. For evaluating impacts from this project a 10 fold margin of safety has been included to determine what changes in incidence may be considered negligible within the study population. This means that changes in the population incidence of any health effect evaluated that is less than one case per year are considered negligible.

Annexure D: Calculations - Nitrogen dioxide

Quantification of Effects - NO_2

Portal emissions

	2030			2040		
Air quality indicator:	NO_2	NO_2	NO_2	NO_2	NO_2	NO_2
Endpoint:	Mortality - All Causes	Mortality - Respiratory	Asthma - ED Hospital admissions	Mortality - All Causes	Mortality - Respiratory	Asthma - ED Hospital admissions
Effect Exposure Duration:	Short-term	Short-term	Short-term	Short-term	Short-term	Short-term
Age Group:	All ages	All ages	1-14 years	All ages	All ages	1-14 years
β (change in effect per 1 μg/m³ NO2) (as per Table 5-11):	0.0006	0.00426	0.00115	0.0006	0.00426	0.00115
Annual Baseline Incidence (as per Table 4-4):						
Annual baseline incidence (per 100,000):	558.7	60.9	1209	558.7	60.9	1209
Baseline Incidence (per person per year):	0.005587	0.000609	0.01209	0.005587	0.000609	0.01209

Sensitive Receptors	Change in Annual Average NO2 Concentration (μg/m³)	Risk	Risk	Risk	Change in Annual Average NO2 Concentration (μg/m³)	Risk	Risk	Risk
Population impacts	-2.28	-8E-06	-6E-06	-3E-05	-1.07	-4E-06	-3E-06	-1E-05
Individual changes - Maximum	1.72	6E-06	4E-06	2E-05	0.98	3E-06	3E-06	1E-05

Ventilation outlets

	2030			2040		
Air quality indicator:	NO_2	NO_2	NO_2	NO_2	NO_2	NO_2
Endpoint:	Mortality - All Causes	Mortality - Respiratory	Asthma - ED Hospital admissions	Mortality - All Causes	Mortality - Respiratory	Asthma - ED Hospital admissions
Effect Exposure Duration:	Short-term	Short-term	Short-term	Short-term	Short-term	Short-term
Age Group:	All ages	All ages	1-14 years	All ages	All ages	1-14 years
β (change in effect per 1 μg/m³ NO2) (as per Table 5-11):	0.0006	0.00426	0.00115	0.0006	0.00426	0.00115
Annual Baseline Incidence (as per Table 4-4):						
Annual baseline incidence (per 100,000):	558.7	60.9	1209	558.7	60.9	1209
Baseline Incidence (per person per year):	0.005587	0.000609	0.01209	0.005587	0.000609	0.01209

Sensitive Receptors	Change in Annual Average NO2 Concentration (μg/m³)	Risk	Risk	Risk	Change in Annual Average NO2 Concentration (μg/m³)	Risk	Risk	Risk
Population impacts	-2.28	-8E-06	-6E-06	-3E-05	-1.11	-4E-06	-3E-06	-2E-05
Individual changes - Maximum	0.84	3E-06	2E-06	1E-05	1.70	6E-06	4E-06	2E-05

Assessment of population incidence - NO_2
Great Western Highway

Health Endpoint:	Mortality - All Causes, Short-term	Mortality - Respiratory, Short-term	Morbidity - Asthma ED Admissions, Short-term
Age Group:	All ages	All ages	1-14 years
β (change in effect per 1 µg/m3 PM) (as per Table 5-22)	0.0006	0.00426	0.00115
2030 Portal emissions			
Total Population in study area:	2375.4	2375.4	2375.4
% population in assessment age-group:	100%	100%	15.6%
Average Δx (µg/m^3):	-2.28	-2.28	-2.28
Baseline Incidence (per 100,000) (as per Table 4-4)	559	61	1209
Baseline Incidence (per person)	0.00559	0.00061	0.01209
Relative Risk:	0.998633	0.990334	0.997381
Attributable fraction (AF):	-1.4E-03	-9.8E-03	-2.6E-03
Change in number of cases in population:	-0.02	-0.01	-0.01
Risk:	-7.6E-06	-5.9E-06	-3.2E-05
2030 Ventilation outlet emissions			
Total Population in study area:	2375.4	2375.4	2375.4
% population in assessment age-group:	100%	100%	15.6%
Average Δx (µg/m^3):	-2.28	-2.28	-2.28
Baseline Incidence (per 100,000) (as per Table 4-4)	403	32	1209
Baseline Incidence (per person)	0.00403	0.00032	0.01209
Relative Risk:	0.998633	0.990334	0.997381
Attributable fraction (AF):	-1.4E-03	-9.8E-03	-2.6E-03
Change in number of cases in population:	-0.01	-0.007	-0.01
Risk:	-5.5E-06	-3.1E-06	-3.2E-05
2040 Portal emissions			
Total Population in study area:	2375.4	2375.4	2375.4
% population in assessment age-group:	100%	100%	15.6%
Average Δx (µg/m^3):	-1.07	-1.07	-1.07
Baseline Incidence (per 100,000) (as per Table 4-4)	396	32	1209
Baseline Incidence (per person)	0.00396	0.00032	0.01209
Relative Risk:	0.999361	0.995469	0.998775
Attributable fraction (AF):	-6.4E-04	-4.6E-03	-1.2E-03
Change in number of cases in population:	-0.006	-0.003	-0.005
Risk:	-2.5E-06	-1.5E-06	-1.5E-05
2040 Ventilation outlet emissions			
Total Population in study area:	2375.4	2375.4	2375.4
% population in assessment age-group:	100%	100%	15.6%
Average Δx (µg/m^3):	-1.11	-1.11	-1.11
Baseline Incidence (per 100,000) (as per Table 4-4)	396	32	1209
Baseline Incidence (per person)	0.00396	0.00032	0.01209
Relative Risk:	0.999334	0.995283	0.998724
Attributable fraction (AF):	-6.7E-04	-4.7E-03	-1.3E-03
Change in number of cases in population:	-0.006	-0.004	-0.006
Risk:	-2.6E-06	-1.5E-06	-1.5E-05

Annexure E: Calculations - Particulates

Quantification of Effects - $PM_{2.5}$ and PM_{10}
2030: Portal emissions

Air quality indicator:	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	DPM
Endpoint:	**Mortality - All Causes**	**Hospitalisations - Cardiovascular**	**Hospitalisations - Respiratory**	**Mortality - All Causes**	**Mortality - Cardiovascular**	**Mortality - Respiratory**	**Morbidity - Asthma ED Admissions**	**Increased risk - lung cancer**
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Short-Term	Short-Term	Based on WHO
Age Group:	≥ 30 years (applied to all ages)	≥ 65 years	≥ 65 years	All ages	All ages	All ages	1-14 years	inhalation unit risk
β (change in effect per 1 μg/m³) (as per Table 5-16)	0.0058	0.0008	0.00041	0.0006	0.00097	0.0019	0.00148	3.40E-05
Annual Baseline Incidence (as per Table 4-4)								(ug/m3)-1
Annual baseline incidence (per 100,000)	558.7	6002.6	3250.9	558.7	133.2	60.9	541.9	
Baseline Incidence (per person per year)	0.005587	0.060026	0.032509	0.005587	0.001332	0.000609	0.005419	

Sensitive Receptors	Change in Annual Average PM10 Concentration (μg/m³)	Change in Annual Average PM2.5 Concentration (μg/m³)	Risk	Risk	Risk	Risk	Risk	Risk	Risk	Risk
Population impacts - Maximum	-0.11	-0.08	-2E-06	-4E-06	-1E-06	-4E-07	-1E-07	-9E-08	-6E-07	-3E-06
Individual changes - Maximum	0.46	0.32	1E-05	2E-05	4E-06	2E-06	4E-07	4E-07	3E-06	1E-05

Quantification of Effects - $PM_{2.5}$ and PM_{10}
2040: Portal emissions

Air quality indicator:	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	DPM
Endpoint:	**Mortality - All Causes**	**Hospitalisations - Cardiovascular**	**Hospitalisations - Respiratory**	**Mortality - All Causes**	**Mortality - Cardiovascular**	**Mortality - Respiratory**	**Morbidity - Asthma ED Admissions**	**Increased risk - lung cancer**
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Short-Term	Short-Term	Based on WHO
Age Group:	≥ 30 years (applied to all ages)	≥ 65 years	≥ 65 years	All ages	All ages	All ages	1-14 years	inhalation unit risk
β (change in effect per 1 μg/m³) (as per Table 5-16)	0.0058	0.0008	0.00041	0.0006	0.00097	0.0019	0.00148	3.40E-05
Annual Baseline Incidence (as per Table 4-4)								(ug/m3)-1
Annual baseline incidence (per 100,000)	558.7	6002.6	3250.9	558.7	133.2	60.9	541.9	
Baseline Incidence (per person per year)	0.005587	0.060026	0.032509	0.005587	0.001332	0.000609	0.005419	

Sensitive Receptors	Change in Annual Average PM10 Concentration (μg/m³)	Change in Annual Average PM2.5 Concentration (μg/m³)	Risk	Risk	Risk	Risk	Risk	Risk	Risk	Risk
Population impacts - Maximum	-0.10	-0.06	-2E-06	-3E-06	-8E-07	-3E-07	-8E-08	-7E-08	-5E-07	-2E-06
Individual changes - Maximum	0.52	0.41	1E-05	2E-05	5E-06	2E-06	5E-07	5E-07	3E-06	1E-05

Quantification of Effects - $PM_{2.5}$ and PM_{10}
2030: Ventilation outlet emissions

Air quality indicator:	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	DPM
Endpoint:	Mortality - All Causes	Hospitalisations - Cardiovascular	Hospitalisations - Respiratory	Mortality - All Causes	Mortality - Cardiovascular	Mortality - Respiratory	Morbidity - Asthma ED Admissions	Increased risk - lung cancer
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Short-Term	Short-Term	Based on WHO
Age Group:	≥ 30 years (applied to all ages)	≥ 65 years	≥ 65 years	All ages	All ages	All ages	1-14 years	inhalation unit risk
β (change in effect per 1 μg/m³) (as per Table 5-16)	0.0058	0.0008	0.00041	0.0006	0.00097	0.0019	0.00148	3.40E-05
Annual Baseline Incidence (as per Table 4-4)								(ug/m3)-1
Annual baseline incidence (per 100,000)	558.7	6002.6	3250.9	558.7	133.2	60.9	541.9	
Baseline Incidence (per person per year)	0.005587	0.060026	0.032509	0.005587	0.001332	0.000609	0.005419	

Sensitive Receptors	Change in Annual Average PM10 Concentration (μg/m³)	Change in Annual Average PM2.5 Concentration (μg/m³)	Risk	Risk	Risk	Risk	Risk	Risk	Risk	Risk
Population impacts - Maximum	-0.114	-0.076	-2E-06	-4E-06	-1E-06	-4E-07	-1E-07	-9E-08	-6E-07	-3E-06
Individual changes - Maximum	0.053	0.043	1E-06	2E-06	6E-07	2E-07	6E-08	5E-08	3E-07	1E-06

Quantification of Effects - $PM_{2.5}$ and PM_{10}
2040: Ventilation outlet emissions

Air quality indicator:	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	DPM
Endpoint:	Mortality - All Causes	Hospitalisations - Cardiovascular	Hospitalisations - Respiratory	Mortality - All Causes	Mortality - Cardiovascular	Mortality - Respiratory	Morbidity - Asthma ED Admissions	Increased risk - lung cancer
Effect Exposure Duration:	Long-term	Short-term	Short-term	Short-Term	Short-Term	Short-Term	Short-Term	Based on WHO
Age Group:	≥ 30 years (applied to all ages)	≥ 65 years	≥ 65 years	All ages	All ages	All ages	1-14 years	inhalation unit risk
β (change in effect per 1 μg/m³) (as per Table 5-16)	0.0058	0.0008	0.00041	0.0006	0.00097	0.0019	0.00148	3.40E-05
Annual Baseline Incidence (as per Table 4-4)								(ug/m3)-1
Annual baseline incidence (per 100,000)	558.7	6002.6	3250.9	558.7	133.2	60.9	541.9	
Baseline Incidence (per person per year)	0.005587	0.060026	0.032509	0.005587	0.001332	0.000609	0.005419	

Sensitive Receptors	Change in Annual Average PM10 Concentration (μg/m³)	Change in Annual Average PM2.5 Concentration (μg/m³)	Risk	Risk	Risk	Risk	Risk	Risk	Risk	Risk
Population impacts - Maximum	-0.10	-0.059	-2E-06	-3E-06	-8E-07	-3E-07	-8E-08	-7E-08	-5E-07	-2E-06
Individual changes - Maximum	0.054	0.047	2E-06	2E-06	6E-07	2E-07	6E-08	5E-08	4E-07	2E-06

Assessment of Increased Incidence - $PM_{2.5}$
Great Western Highway

	Primary Indicators			Secondary Indicators		
Health Endpoint:	**Mortality - All Causes, Long-term**	**Hospitalisations - Cardiovascular, Short-term**	**Hospitalisations Respiratory, Short-term**	**Mortality - Cardiovascular, Short-term**	**Mortality - Respiratory, Short-term**	**Morbidity - Asthma ED Admissions - Short-term**
Age Group:	≥ 30 years (applied to all ages)	≥ 65 years	≥ 65 years	All ages	All ages	1-14 years
β (change in effect per 1 µg/m3 PM) (as per Table 5-16)	0.0058	0.0008	0.00041	0.00097	0.0019	0.00148
2030 Portal emissions						
Total Population in study area:	2375.4	2375.4	2375.4	2375.4	2375.4	2375.4
% population in assessment age-group:	100%	26%	26%	100%	100%	15.6%
Average Δx (µg/m^3):	-0.0767	-0.0767	-0.0767	-0.0767	-0.0767	-0.0767
Baseline Incidence (per 100,000) (as per Table 4-4)	559	6003	3251	133.2	60.9	541.9
Baseline Incidence (per person)	0.00559	0.06003	0.03251	0.00133	0.00061	0.00542
Relative Risk:	0.999555	0.999939	0.999969	0.999926	0.999854	0.999886
Attributable fraction (AF):	-4.4E-04	-6.1E-05	-3.1E-05	-7.4E-05	-1.5E-04	-1.1E-04
Change in number of cases in population:	-0.006	-0.002	-0.0006	-0.0002	-0.00021	-0.0002
Risk:	-2.5E-06	-3.7E-06	-1.0E-06	-9.9E-08	-8.9E-08	-6.2E-07
2030 Ventilation outlet emissions						
Total Population in study area:	2375.4	2375.4	2375.4	2375.4	2375.4	2375.4
% population in assessment age-group:	100%	26%	26%	100%	100%	15.6%
Average Δx (µg/m^3):	-0.0760	-0.0760	-0.0760	-0.0760	-0.0760	-0.0760
Baseline Incidence (per 100,000) (as per Table 4-4)	1026	9235	3978	113.4	49.4	1209.0
Baseline Incidence (per person)	0.01026	0.09235	0.03978	0.00113	0.00049	0.01209
Relative Risk:	0.999559	0.999939	0.999969	0.999926	0.999856	0.999888
Attributable fraction (AF):	-4.4E-04	-6.1E-05	-3.1E-05	-7.4E-05	-1.4E-04	-1.1E-04
Change in number of cases in population:	-0.01	-0.003	-0.0008	-0.0002	-0.0002	-0.0005
Risk:	-4.5E-06	-5.6E-06	-1.2E-06	-8.4E-08	-7.1E-08	-1.4E-06
2040 Portal emissions						
Total Population in study area:	2375.4	2375.4	2375.4	2375.4	2375.4	2375.4
% population in assessment age-group:	100%	26%	26%	100%	100%	15.6%
Average Δx (µg/m^3):	-0.0600	-0.0600	-0.0600	-0.0600	-0.0600	-0.0600
Baseline Incidence (per 100,000) (as per Table 4-4)	1026	9235	3978	98.7	49.4	1209.0
Baseline Incidence (per person)	0.01026	0.09235	0.03978	0.00099	0.00049	0.01209
Relative Risk:	0.999652	0.999952	0.999975	0.999942	0.999886	0.999911
Attributable fraction (AF):	-3.5E-04	-4.8E-05	-2.5E-05	-5.8E-05	-1.1E-04	-8.9E-05
Change in number of cases in population:	-0.008	-0.003	-0.0006	-0.0001	-0.0001	-0.0004
Risk:	-3.6E-06	-4.4E-06	-9.8E-07	-5.7E-08	-5.6E-08	-1.1E-06
2040 Ventilation outlet emissions						
Total Population in study area:	2375.4	2375.4	2375.4	2375.4	2375.4	2375.4
% population in assessment age-group:	100%	26%	26%	100%	100%	15.6%
Average Δx (µg/m^3):	-0.0588	-0.0588	-0.0588	-0.0588	-0.0588	-0.0588
Baseline Incidence (per 100,000) (as per Table 4-4)	1026	9235	3978	98.7	49.4	1209.0
Baseline Incidence (per person)	0.01026	0.09235	0.03978	0.00099	0.00049	0.01209
Relative Risk:	0.999659	0.999953	0.999976	0.999943	0.999888	0.999913
Attributable fraction (AF):	-3.4E-04	-4.7E-05	-2.4E-05	-5.7E-05	-1.1E-04	-8.7E-05
Change in number of cases in population:	-0.008	-0.003	-0.0006	-0.0001	-0.0001	-0.0004
Risk:	-3.5E-06	-4.3E-06	-9.6E-07	-5.6E-08	-5.5E-08	-1.1E-06